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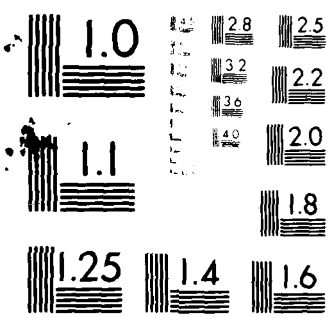

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ABSTRACT

DENNIS FREEMAN NAUGLE
(Under the direction of Dr. Donald L. Fox)

CONTROL OF AIR POLLUTION FROM AVIATION:
THE EMISSION STANDARD SETTING PROCESS

Air pollutant emissions from aviation sources are a small but increasing part of all emissions on a national scale. The United States Environmental Protection Agency first issued emission standards for aircraft engines in 1973 and has repeatedly changed the control regulations since that time. Critics claim the standards are too stringent and do not solve any real air pollution problems. Proponents argue that ambient air standards for oxidants and other pollutants are frequently violated and will not be achieved unless control technology is applied to many sources - including those the size of airports.

The objective of this research is to evaluate the potential effects of aviation on ambient air quality with special emphasis on the requirement and techniques for setting aviation control standards. A logical framework called the "hypothesis decision model" was developed. It offers a structured way of dealing with complex issues. Application of the model focuses on aircraft sources but a generic version is also proposed. Adoption would explicitly document the manner that technical evidence is considered in a variety of decisions concerning the establishment of emission standards.

Various techniques to evaluate and set aviation emission standards are compared. They are envisioned as additional alternatives to the exclusive application of maximum control technology. Integration of results from these techniques as well as findings from the hypothesis decision model lead to the overall study recommendations and conclusions.

Analyses of all current evidence suggest that aviation sources are not a direct cause of health and welfare effects. Conversely, studies have not proven that aviation sources are insignificant as contributors to air pollution problems. A wide range of policy choice exists in the establishment of specific emission standards. Stringent standards for aircraft hydrocarbon emissions are suggested since the control technology is available and cost effective. Standards for the control of carbon monoxide from aircraft engines should be relaxed or eliminated. There is simply no problem which would be solved by such a regulation. Aviation standards for oxides of nitrogen (NO_x) are not now suggested. The difficulty in meeting NO_x control technology, high cost of control, and absence of a link between aircraft emissions and air quality effects are all key issues which should be addressed in the future.

CONTROL OF AIR POLLUTION FROM AVIATION:
THE EMISSION STANDARD SETTING PROCESS

by

Dennis F. Naugle

A Dissertation submitted to the faculty of The University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Environmental Sciences and Engineering.

Chapel Hill

1981

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES IN APPENDICES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES IN APPENDICES

LIST OF FIGURES IN APPENDICES (Continued)

PREFACE

Material presented in this work covers a broad spectrum of topics ranging from the philosophical aspects of air quality management to the engineering of gas turbine engine emission control alternatives. Few readers are expected to have enough time or interest to read it cover to cover. A departure is therefore made from the normal format where all issues are discussed in the text of the body of the dissertation.

A graphical approach or "model", as shown in Figure V-1, is used to portray the inter-relationship of many technical issues of interest in the emission standard setting process for aviation sources. Descriptions and summary conclusions of these issues are in tables rather than in the text. Supporting details are in appendices keyed to the graphical models. This format is intended to emphasize a systems concept as applied to the standard setting process. It will hopefully prevent the reader from becoming enmeshed in complex technical details, which are a necessary part of any standard setting process, yet losing sight of the relevancy of these details toward the overall goal of standard setting.

A guide is suggested below to assist review of this work by various levels of readers:

Level/Interest of Reader	Locations in Report
1. Executive Overview	-Chapters I, VI, X, XI
2. General Interest in Emission Standard Setting	-Chapters V, VII, VIII and Appendix A
3. General Interest in Aviation and Air Quality	-Chapters I, II, VI, IX, X, XI
4. Specific Interest in an Aviation Technical Issue	-Chapter V to find the particular issue in Appendix A (e.g. Aviation control technology is in Appendix A.4 and A.7, effects of aviation on air quality are in Appendix A.3 and A.5).
5. Detailed Interest in Aviation Emission Standard Setting	-All chapters in sequence, Figure A-1, and specific evidence on various issues as shown in the detailed test of hypothesis tables in Appendix A.

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Each member of my Doctoral Committee (listed on the title page) for project direction and review of the Dissertation;

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Special credit is due to my Dissertation Advisor, Dr. Donald L. Fox. His friendship, advice, and dedication were indispensable during all phases of this project.

I especially want to thank my wife, Darlene, for her continuous support throughout the Doctoral program and for typing the draft and final manuscripts. Without her willingness to work long hours in the typing and editing phases, this Dissertation could not have been published in a timely manner.

GLOSSARY

A/C -- Abbreviation for aircraft in charts.

Air Pollution Control Philosophy -- Used in this work to describe the basic approaches to air quality management.

BACT -- Best available control technology. Used in this work to mean judgements of the lowest emissions technologically practicable.

Control Techniques -- Procedures or equipment which can reduce air pollution emissions.

Emission Standard Setting Process -- Used to describe all activities and issues required to set emission standards.

Event Trees -- Used in this work to describe methodology which quantitatively estimates probabilities of air quality concentrations. Uncertainties in source emission rates, control variations, atmospheric dispersion, and prediction errors are considered.

Hypothesis Decision Model -- A logical framework proposed as a structured way of dealing with complex emission standard setting issues.

IUE -- In Use Engines which are effected by the proposed EPA retrofit emission standard.

LTO -- Aircraft Landing and Takeoff cycle. Only emissions in the airport vicinity are considered in this study. The LTO cycle is composed of average times in the approach, taxi-in, start-up, taxi-out, takeoff, and climb-out aircraft modes.

NAAQS -- National Ambient Air Quality Standards. Further description in Table A-1.

NCE -- Newly Certified Engines to which the most stringent regulations may be applied.

NME -- Newly Manufactured Engines which have already been certified for air worthiness.

Techniques for Standard Setting -- Used to describe quantitative methods to evaluate the utility or set the level of aviation emission controls.

CHAPTER I

INTRODUCTION

The Federal Clean Air Act, Section 231, directs the Environmental Protection Agency (EPA) Administrator to issue emission standards for:

> "...Aircraft engines which in his judgement causes or contributes to, air pollution which may reasonably be anticipated to endanger public health or welfare".

Given that strong congressional mandate, EPA first issued regulations for civil aircraft engine emissions in 1973. Numerous revisions have since occurred and are currently under consideration. Debate over the need and methods to set standards for the control of air pollution from aviation has continued for over ten years without resolution.

A. Aircraft Standards In Perspective

Critics suggest that the Federal regulations for aircraft engines are overly complex, too stringent, and won't solve any air pollution problems. Aviation related sources, including aircraft, support equipment, and automobiles near busy airport terminals are not considered as primary components of regional and local air pollution problems. Aircraft emissions on the ground and within the lower "mixing layer" of the atmosphere account for less than 1% of all anthropogenic emissions in the United States. Regional percentages range from a fraction of 1% to 3% depending on the pollutant specie, specific airport, and geographical region considered. A link between aircraft emissions and health and welfare effects has never been demonstrated.

Proponents of aircraft regulations argue that ambient air pollution standards for pollutants such as oxidants are frequently violated and cannot be met unless the best available technology is applied to many sources including those the size of airports. Busy airports annually emit tens of thousands of tons of carbon monoxide (CO), and several thousands of tons of total hydrocarbons (THC), and oxides of nitrogen (NO_x). Although not directly applicable, aviation sources are far greater than the definition of a "major stationary source" or "major emitting facility" as one which emits over 100 tons per year of any pollutant in the Clean Air Act, Section 302. The busiest airports are usually in close proximity to densely populated and polluted urban areas. Therefore, simple analyses do not allow airports to be clearly dismissed as insignificant contributors to local air pollution levels.

Three factors are paramount in consideration of future aviation control standards:

1. All past and currently proposed standards are complex in format (Chapter IV). They result from judgements of the "best available control technology". These judgements are based on difficult engineering and policy considerations. Since past projections of control levels and compliance deadlines have proven to be unrealistic, some changes seem inevitable.

2. Recent cost effectiveness studies have indicated that control costs are consistent with other mobile and stationary sources for some pollutant species but not other species. Projected control costs of up to several billion dollars over the next ten years lead to questions of whether the benefits outweigh the costs.

3. Considerable research to quantify the potential air quality benefits from aviation emission reductions has been conducted throughout the 1970's. Results have not clearly substantiated the early conclusion that aviation sources cause localized "hot spots" which are detrimental to health and welfare. The air quality improvements from implementation of expensive emission control programs are therefore not clear.

Various control strategies for aviation emissions have consequently been proposed, legislated, and redirected over the past decade. These changes will persist as long as there are differences of opinion in the feasibility of engineering controls, and even the basic need for such controls.

B. Research Objectives and Task Areas

The thesis of this author is that a satisfactory resolution to aviation standard setting issues will come not from a few key scientific studies, but from an integration of the hundreds of past studies. The objective of this research is to evaluate the potential effects of aviation on ambient air quality with special emphasis on the requirement and techniques for setting control standards. This involves extensive literature review and analyses plus original work in the development of a standard setting model and alternative techniques to derive recommended control strategies for aviation sources. Five task areas were identified at the early stages of this work.

Task 1 - Literature Review

A comprehensive literature search has been conducted and published as a paper at an Air Pollution Control Association Annual Meeting (Naugle, 1980). Nearly 200 references have been analyzed and collectively form one of the most complete libraries concerning the evaluation of ambient air pollution from aviation sources. Additional works have also been reviewed during the course of this study, mostly in areas of standard setting, aircraft engine emission test procedures, combustion chemistry, aircraft engine engineering controls, and aviation emission cost of control studies. Summaries of these works have been used but no attempt has been made to duplicate the detailed analyses done by others.

Task 2 - Model Development

A logical framework called the "hypotheses decision model" is proposed and described in Figure V-1 of this work. The function of the model is to show the inter-relationship of the many technical issues involved in the aviation emission control standard setting process. A specific hypothesis statement is made for each key issue. While this model is designed for aviation sources, it offers a structure for analysis of other sources, particularly where the resulting air quality effect is marginal or controversial.

Task 3 - Model Application and Evaluation

The hypothesis decision model is specifically applied to the aviation emission standard setting process. Each hypothesis along the primary pathway is evaluated by consideration of all evidence in the literature and by calculations from the techniques described in Task 4. Conclusions are synthesized from all relevant technical data. The primary pathway in the model is defined by a true or false conclusion for each hypothesis. It may or may not be along the "null hypothesis" route shown as double lines in Figure V-1. If true or false conclusions are not objectively possible, the pathway is established by assumption or by consideration of both subsequent pathways.

Although not planned in the early stages of this work, Chapter VII was added as a preliminary evaluation of the proposed model. A more complete evaluation would be possible in the future after application to additional emission source categories.

Task 4 - Alternative Standard Setting Techniques

Techniques to evaluate and set aviation emission standards are compared and contrasted. They are envisioned as alternatives to the exclusive use of the best available control technology for all pollutants. Published data and original calculations are both used for comparisons using current aviation emission and operational data. Techniques evaluated include best available control technology, empirical models based on emissions, air quality simulation models, cost effectiveness computations, and "event trees". Findings from all techniques rather than any single technique are presented in Chapter VIII.

Task 5 - Recommendations of Aviation Control Options

Aircraft emission projections through the year 2000 are analyzed in Chapter IX. Several levels of control ranging from no control to the stringent standards proposed by EPA in 1978 are included. Conclusions and recommendations are made from the many issues and options addressed in this work. A summary of the overall results have been published and are presented in Appendix D (Naugle and Fox, 1981). Supporting details as well as more recent findings are included in this work. The hypothesis decision model and various standard setting techniques are used to suggest the pollutants and the degree of control which should be emphasized in future aviation emission standards. Complete agreement of conclusions in this work cannot be expected by all parties on all issues. However, the explicit consideration of evidence in this work should tend to focus future debate on specific data or judgement differences. Some scientific gaps which cause uncertainty in the need for emission standards are also identified. Decisions of how to deal with the remaining uncertainty as well as with political and other considerations must still be made by policy-makers.

CHAPTER II

BACKGROUND

Several studies in the late 1960's and early 1970's suggested that aircraft can be significant contributors to the regional air pollution burden. Studies included ambient air quality measurements at a few airports, air quality dispersion modelling, annual emissions comparisons, and emission density comparisons. Based on data available at that time, EPA concluded that aircraft exerted an intense, localized impact on air quality which could contribute to a significant health hazard (U.S. EPA, 1972a). The reasoning was that controls on automobiles and stationary sources might not adequately reduce local concentrations to meet the ambient air quality standards unless aircraft emissions were also reduced. Promising control techniques included modification of ground operations, better maintenance procedures, new combustion technology, and the retrofit of older engines with "clean combustors". Also, a general feeling existed that Federal aircraft emission regulations would provide a valuable technology "forcing function" which would not otherwise occur.

Opposing viewpoints in this time frame (late 1960's and early 1970's) were that the aircraft regulations were too stringent for the compliance deadlines, too expensive, insignificant toward meeting air quality goals, and uncertain with respect to safety considerations. Studies used to evaluate the impact of aircraft were often considered tenuous and later shown to be inaccurate (Yamartino and Rote, 1979). Ambient air quality measurement studies conducted at Los Angeles

Airport and Washington National Airport were ambiguous. Attribution of measured levels to either aircraft or non-aircraft sources was extremely difficult. Dispersion model results were based on a newly developed model by Northern Research and Engineering Corporation (Platt and Bastress, 1971) which was never thoroughly tested and, therefore, subject to considerable uncertainty, both in theory and in application with the available input data.

Superimposed on the evidence both for and against setting aircraft emission standards was the overall "mood" of the legislators, administrators and the United States public. This was an era of strong environmental awareness which was conducive to stringent regulation with ambitious compliance schedules. The arguments against aircraft regulations were superficially similar to those recently used by the automotive industry. Overwhelming scientific evidence over many years indicated that automobiles were a serious source of pollution which could be drastically reduced. However, the automotive industry continued to claim controls were unnecessary, unfeasible, and too expensive. Automotive emission control technology was implemented only when mandated by strong regulations in the Clean Air Act of 1970 (CAA, 1970). In the opinion of this author, objectively weighing the need for aircraft emission control regulations was clouded by the apparent analogy to automotive legislation. Avoiding aircraft standards shortly after applying rigid control standards for automobiles would have appeared inequitable, irrespective of the technical evidence.

Aircraft engine emission control standards were consequently established in 1973. A relaxation of implementation dates and control levels has occurred several times since then. The latest revision was proposed in 1978 and is still under consideration. Engine manufacturers submit that standards were technologically too stringent. The Clean Air Act will soon come up for congressional review and a number of programs could be re-evaluated. While the National Commission on Air Quality recently recommended that EPA should continue to develop new source performance standards, it also endorsed the current EPA philosophy of not requiring the most stringent technology available (NCAQ, 1981, p. 2.2-17 and p. 3.7-8). A detailed account of the past standard setting process and the standards themselves are presented in the following two chapters. These discussions establish essential groundwork for the standard setting process proposed in this work starting in Chapter V.

CHAPTER III

REVIEW OF LEGISLATIVE HISTORY

The evolution of Federal aircraft emission control legislation is presented in this chapter to enable a more thorough understanding of both the past standard setting process and range of alternative actions which have been considered. Both the complexity of these standards and number of revisions are indicators of the high difficulty in setting standards at best available control technology levels. Table III-1 presents relevant legislation standards and issues. It serves as an outline for discussion in this chapter.

The Clean Air Act of 1963 established the fact that the Federal government was actively concerned with air pollution. It initiated the flow of technical material and encouraged scientific exploration of many areas relating to the analysis, and control of air pollution problems. The 1965 "Motor Vehicle Air Pollution Control Act" recognized the fact that automobiles were a serious cause of air pollution problems and that legislation by individual states was not an effective way of controlling the problems. The precedent for Federal emission control standards was therefore established and later applied to aircraft as well as some stationary sources. The first reference to aircraft as a source which may require controls was in the "Air Quality Act of 1967". This act required the Secretary of Health, Education and Welfare to study the need and feasibility of controlling aircraft emissions. A variety of research efforts were stimulated as a result.

TABLE III-1
AIRCRAFT EMISSION CONTROL LEGISLATION

DATE	LEGISLATION (Including Proposed Actions)	SUBSTANTIVE ISSUES
Dec. 17, 1963	P.L.* 88-206 - "Clean Air Act of 1963".	-Original legislation which gave regulatory powers to the Federal government. Powers were limited to interstate air pollution on an "ad hoc" basis.
Oct. 20, 1965	P.L. 89-272 - "Motor Vehicle Air Pollution Control Act".	-Precedence for Federal, rather than State, control of a particular source of pollution.
Nov. 21, 1967	P.L. 90-148 - "Air Quality Act of 1967" (Section 211b).	-First mention of aircraft in air pollution legislation. -Required study of feasibility of controlling aircraft emissions by national emission standards. -Required the Secretary to provide this study and his recommendations to Congress within 1 year from this Act.
Dec. 31, 1970	P.L. 91-604 "Clean Air Amendments of 1970". (Section 102)	-Gave authority to EPA Administrator instead of Secretary of HEW.
	(Section 109)	-Required EPA to issue national primary and secondary ambient air quality standards.
	(Section 231)	-Directed EPA to set aircraft emission standards subject to requirements of public health and welfare and limited by safety considerations. -Subsequently used as authority for all later EPA rule making.
	(Section 232)	-Required DOT to enforce aircraft emission standards.
	(Section 233)	-Limited states from adopting or enforcing standards different than the national aircraft emission standards.
Dec. 12, 1972	** 37FR26488 - "Aircraft and Aircraft Engines: Proposed Standards for Control of Air Pollution".	-Proposed various aircraft engine emission standards and test procedures with deadlines ranging from 1/1/74 to 1/1/79.
Dec. 12, 1972	37FR26502 - "Ground Operation of Aircraft to Control Emissions: Advance Notice of Proposed Rulemaking".	-Considered rulemaking to reduce emissions by altering aircraft taxi procedures at large "Class A" commercial airports. This action solicited comments prior to an EPA judgment on the advisability of rulemaking.
July 17, 1973	*** 40CFR Part 87 (or 38FR19088) "Control of Air Pollution from Aircraft Engines: Emission Standard and Test Procedures for Aircraft" (Sections 87.10-87.52).	-Promulgated standards for civil aircraft for: 1) Fuel venting from gas turbine engines. 2) HC, CO, NO_x and smoke from turbine engines. 3) HC, CO, NO_x from piston aircraft. 4) HC, CO, NO_x from Onboard auxiliary power units.
July 22, 1974	39FR26653 "Proposed Regulations on Control of Air Pollution from Supersonic Aircraft".	-Proposed standards which allow for inherently high emissions of SST type aircraft engines. -HC, CO, NO_x and smoke controls are proposed for 1979 or 1981.
Aug. 16, 1976	41FR34722 "Control of Air Pollution from Aircraft and Aircraft Engines; Supersonic Aircraft".	-Promulgate standards for SST type aircraft engines.
March 24, 1978	43FR12615 "EPA Proposed Revisions to Gaseous Emissions Rules for Aircraft and Aircraft Engines.	-Proposals to: 1) Withdrawal of standards for general aviation aircraft. 2) Withdrawal of standards for auxiliary power units. 3) Two to five year delay in implementing standards depending on specific engine and pollutant classification. 4) Relax NO_x standard and delete NO_x retrofit requirement. 5) Re-examine the need for NO_x standard, prior to implementation of this proposed standard.
Nov. 6, 1979	44FR64266 "Control of Air Pollution from Aircraft Engines; Extension of Compliance Date for Emission Standards Applicable to JT3D Engines".	-Extends compliance date for JT3D smoke emission standards from September 1, 1981, to January 1, 1985.
Jan. 7, 1980	45FR1419 "Control of Air Pollution from Aircraft and Aircraft Engines; Amendments to the Emission Standards for Aircraft Engines".	-Withdraws gaseous emission standards for all opposed-piston aircraft engines and auxiliary power units.

*P.L. = Public Law
**FR = Volume, Federal Register, Page Number.
***CFR = Title, Code of Federal Regulations, Part Number, Section Number.

The Clean Air Act Amendments of 1970 is the prime legal authority and driving force behind the setting of aircraft standards. Authority to set numerical control limits was given to the administrator of the newly created Environmental Protection Agency. It required the establishment of national ambient air quality standards and directed EPA to set aircraft emission standards consistent with these ambient levels. The Department of Transportation (DOT), through their Federal Aviation Administration (FAA), was directed to insure that aircraft safety was not compromised and to enforce the standards set by EPA. Due to the small numbers of aircraft engine manufacturing facilities and the cost and complexity in engine designs, individual states were prevented from adopting standards which were different from the national aircraft emission standards.

EPA formally proposed the aircraft standards on December 12, 1972. Compliance schedules ranged from January 1, 1974 to January 1, 1979. Controls were proposed to limit fuel venting emissions, piston engine crankcase emissions, gaseous and smoke emissions from both in-use and new aircraft engines. Test procedures were outlined to determine compliance with the numerical limits. The standards were set at what EPA considered as the best available control technology.

In a companion document on December 12, 1972, EPA proposed to reduce emissions by altering aircraft and ground operating procedures at larger "Class A" airports. Ground procedure changes had the advantage of immediately lowering emissions while the gradual phase-in of low pollution aircraft engines could be implemented. Because aircraft engines have critical design parameters based on maximum efficiency at high thrust settings, THC and CO emissions are greatest from low thrust modes. Early estimates were made that 50%-70% of these aircraft emissions at airports could be reduced by operational changes. This would involve either towing the aircraft to the takeoff runway or taxiing aircraft with fewer operating engines in a higher thrust mode. This proposal was never promulgated, however, apparently due to uncertain safety and perhaps cost considerations.

After public hearings in Boston and Los Angeles, standards for the control of emissions from aircraft and aircraft engines were published on July 17, 1973. The standards were relaxed from the proposed ones to become essentially equivalent to the design goals set by the United States Air Force (USAF) and National Aeronautics and Space Administration (NASA). At this point in time, there was an apparent agreement among these two Federal agencies and EPA concerning the "best available control technology". The proposed crankcase emissions control for piston engines were not adopted due to safety considerations. Exhaust emission standards for these piston engines were retained as proposed but the effective compliance dates were delayed. Changes in engine classifications were also made between the proposed and adopted standards. A new category was established for the supersonic transport (SST) aircraft engines. These engines are inherently more polluting than engines of a similar generation since they cannot use the "high bypass ratio turbofan principle" due to the frontal drag induced by the large diameter fans. Total hydrocarbon and carbon monoxide standards were set more lenient than other engines to agree with current technology for this type engine.

The standards adopted in July 1973 also included a proposed retrofit program (standards applied to in-use rather than newly built engines) for gaseous emissions which was not in the earlier proposal. A net decrease in total emissions was seen between the original 1972 proposed standards and the adopted standards which were more lenient but included a proposed retrofit program. Total net engine reductions by 1979 were established as follows:

1. Engines with less than 8,000 pounds thrust:
   (e.g. Lear Jet, Lockheed Jetstar, and Lockheed Electra)

   THC - 80%
   CO - 60%
   NO_x - 20%

2. Engines with over 8,000 pounds thrust:
   (e.g. Boeing 707, 727, 737, 747, DC-8, DC-9)

   THC - 60%
   CO - 70%
   NO_x - 50%

3. All non-radial piston engines:

   THC - 30%
   CO - 50%
   NO_x - Maintenance of current levels

4. All smoke levels below levels of visibility.

The EPA cost estimates for all but the proposed retrofit program were $141 million over a ten year period. This was equivalent to a one-tenth of 1% increase in passenger ticket costs.

Controlled emission levels for the SST-type aircraft were proposed in July 1974. These reductions were shown to have a significant effect on the John F. Kennedy Airport emissions projected for the year 1990. This projection is now obsolete, however, since the number of operating SST aircraft never reached levels previously anticipated.

Finally, a major revision to the aircraft emission standards was proposed in March 1978. These changes are still being debated. The most controversial aspects of the proposed changes deal with the cost effectiveness of the NO_x emission controls and whether they are even needed. Even though this proposal deletes the NO_x retrofit requirement, relaxes the controlled emission levels, and postpones implementation until 1984 or later, costs up to several billion dollars over ten years are projected (Day and Bertrand, 1978). The ten fold increase in the cost of control estimate since 1973 is due to thorough economic analysis as well as real cost increases which have taken place.

Rulemaking on January 7, 1980 revoked all standards applicable to general aviation aircraft because:

1. A recent study indicates that the total contribution of general aviation airports to the surrounding regional air quality is small (Jordan, 1977a).

2. The cost per ton of abated emissions is considerably higher than for other mobile and stationary sources. For example, piston aircraft controls for hydrocarbons are $2,300 to $8,000 per ton compared to $950 per ton for other available sources.

Also, standards for auxiliary power units onboard aircraft have been withdrawn because:

1. NO_x control technology could not be demonstrated.

2. The cost of CO control, both to industry and to government (apparently in the standard enforcing process) do not warrant the minimal CO reductions.

3. THC standards are already being met.

The resulting emission standards, after all the above adopted changes and proposed revisions have been incorporated, are the subject of the next chapter.

CHAPTER IV

STANDARDS FOR AIRCRAFT AND AIRCRAFT ENGINES
(From the Notice of Proposed Rulemaking,
March 24, 1978)

Numerical standards for control of emissions from aircraft engines are difficult to present in a clear yet comprehensive format. The elaborate nature of the standards is due to the fact that they have been derived from the "best available control technology" which is dependent on the size, vintage, and design characteristics of the aircraft engines. All engines have been categorized into six major classifications as shown in Table IV-1. Numerical standards using these classifications are presented in a simplified format in Tables IV-2 and IV-3. The complete set of standards, proposed standards, and testing methods are over 19 pages and are therefore not included (Federal Register, 1978).

All pollutant species in the standards are discussed in this chapter for completeness. Later chapters will focus on CO, THC, and NO_x which are the most controversial species.

Evaporative hydrocarbon emissions from fuel venting have already been implemented as shown in Table IV-2. In this case, venting refers to intentional fuel drainage from fuel nozzle manifolds after engine shutdown. Controls have simply prevented the fuel from escaping to the atmosphere. Fuel tank working losses from aircraft refueling are not included in these standards.

The particulate matter standards in this table are based on a Smoke Number scale rather than a mass scale for two reasons. First, numerous early complaints dealt with objections to the visible plume

TABLE IV-1
ENGINE CLASSIFICATIONS

CLASS	CRITERIA	EXCEPTIONS
P2	All Turboprop Engines	
T1	Rated Thrust < 35,600 Newtons	Engines of Class T5
T2	Rated Thrust > 35,600 Newtons	Engines of Classes T3, T4, & T5
T3	Engines of JT3D Model Family	
T4	Engines of JT8D Model Family	
T5	Engines designed for supersonic aircraft	

TABLE IV-2

FUEL VENTING AND SMOKE AIRCRAFT ENGINE EMISSION STANDARDS
(AS OF PROPOSED REVISIONS, MARCH 24, 1978)

EMISSION STANDARDS	APPLICABLE ENGINES	DEADLINES
No Fuel Venting	• New & In-Use Engines of Classes T2,T3,T4, & T5	January 1, 1974
	• New & In-Use Engines of Classes T1 and P2	January 1, 1975
Smoke Number = 30 or less	• New & In-Use Engines of Class T4	January 1, 1974
Smoke Number* = $79 (rO)^{-0.265}$ or less	• New & In-Use Engines of Class T2 and with rO = >129	January 1, 1976
	• New Engines of Class T5	January 1, 1980
	• New Engines of Classes T1,T2, T3 and T4	January 1, 1981
Smoke Number = 25 or less	• All New Engines of Class T3	January 1, 1978
	• In-Use Engines of Class T3 as follows:**	
	-25% of operational engines	January 1, 1981
	-50% of operational engines	January 1, 1983
	-100% of operational engines	January 1, 1985
Smoke Number = $277(rO)^{-0.280}$	New Engines of Class P2	January 1, 1979
Smoke Number* = $79(rO)^{-0.265}$	In-Use Engines of rO* = 53 or greater	January 1, 1985

*rO is rated output in kilonewtons thrust
**Some exceptions allowed for scheduled replacement engines or aircraft

TABLE IV-3

GASEOUS EMISSION STANDARDS FOR AIRCRAFT ENGINES
(AS OF PROPOSED REVISIONS, MARCH 24, 1978)

EMISSION STANDARDS	APPLICABLE ENGINES	DEADLINES
HC = < 30.7 grams/kilonewton CO = < 237.0 grams/kilonewton NO_x = < 70.8 grams/kilonewton	New Engines of Class T5	---- January 1, 1980
HC = or less than: $26.510 \times 10^{-0.006637 rO}$ (grams/kilonewton) CO = or less than: $169.47 \times 10^{-0.007462 rO}$ (grams/kilonewton)	New Engines of Classes T1, T2, T3 & T4 with: $27 \leq rO^{*} < 90$ In-Use Engines of Classes T2 & T4 with: $53 \leq rO^{*} < 90$	 ---- January 1, 1981 ---- January 1, 1985
HC = or less than: 6.7 grams/kilonewton CO = or less than: 36.1 grams/kilonewton	New Engines in Classes T2, T3, and T4 with: $90 \leq rO^{*}$ In-Use Engines in Classes T2 & T4 with: $90 \leq rO^{*}$	 ---- January 1, 1981 ---- January 1, 1985
NO_x = or less than -33.0 grams/kilonewton ----- $-33.0\,(rPR/25)^{0.5}$ ----- $\exp(rT3/288.15-2.774)$	New Engines of Classes T1, T2, T3 & T4 with: $rPR \leq 25$ with: $25 < rPR$	January 1, 1984
HC = < 3.3 grams/kilonewton CO = < 25.0 grams/kilonewton NO_x = < 33.0 grams/kilonewton	Newly Certified Engines In: Classes T1, T2, T3 or T4 with $27 \leq rO^{*}$;	January 1, 1984
HC = < 7.8 grams/kilonewton CO = < 61.0 grams/kilonewton NO_x = < 39.0 grams/kilonewton	Class T5:	January 1, 1984
HC = < 0.045 grams/kilowatt CO = < 0.34 grams/kilowatt NO_x = < 0.45 grams/kilowatt	Class P2 with: $rO \geq 2000$ kilowatts	January 1, 1984

*rO = rated Output in Kilonewtons
**rPR = rated Pressure Ratio
HC = Total Hydrocarbons, CO = Carbon Monoxide, NO_x = Oxides of Nitrogen

ENGINE CLASSIFICATIONS

CLASS	CRITERIA	EXCEPTIONS
P2	All Turboprop Engines	
T1	Rated Thrust < 35,600 Newtons	Engines of Class T5
T2	Rated Thrust > 35,600 Newtons	Engines of Classes T3, T4, & T5
T3	Engines of JT3D Model Family	
T4	Engines of JT8D Model Family	
T5	Engines designed for supersonic aircraft	

from aircraft. Health effects due to the mass of particulate matter have not been considered to be a problem from aircraft. Second, the mass of particulate emissions is especially difficult to measure. This is due to the high temperature complex flow field where measurements must be made. Aerosols may form in sampling lines in a way which does not occur in the atmosphere. Complex concentration gradients in the exhaust flow also make acquiring a representative sample a painstaking task. Standards are therefore based on a measured "smoke number" which can more easily be measured by the impaction of particles on filter paper.

Current smoke number standards are shown in Table IV-2. They are a function of engine rated output (rO) on the philosophy of controlling the exhaust emissions just enough to make them invisible. Due to the negative exponential function in this standard, higher rated output levels will result in a lower allowable smoke number. Theoretically, this will limit the particle densities through the optical path length and render the resulting plume invisible. Most of the older engines have already been retrofitted with "smokeless" combustors and the newer engines have been designed as such. These standards give DOT enforcement authority for any exceptions.

Gaseous emission standards are shown in Table IV-3. Standards and compliance deadlines vary with the engine stage of development as indicated by "new" for newly manufactured engines (NME), "newly certified" for newly certified engines (NCE), and "in-use" for in-use engines (IUE) which require a retrofit program. The general structure of the standards is to require THC and CO controls on NME by 1981 and on IUE by 1985. NO_x control on NME are required by 1984. The

1984 NCE standards include NO_x and more stringent THC and CO controls. Details within this general structure are given below.

Two sets of THC and CO standards are shown for engines with rated output above and below 90 kilonewtons. This recognizes that higher thrust engines can be designed with greater overall thermal efficiency. Since THC and CO are products of inefficiency, better control technology exists for these pollutants in these larger engines. Controls are even more stringent in the NCE class to reflect greater anticipated capabilities of engines with completely new designs. The exception is the T-5 class for SST aircraft where higher efficiency turbofan engines cannot be used.

Controls for NO_x are a more difficult problem since they are not formed by incomplete combustion but by peak combustion temperatures for high residence times. Standards are therefore varied with rated pressure ratio (rPR) for "new" engines. Engines with higher pressure ratios will operate at higher combustion temperatures and, therefore, tend to produce more NO_x (from the high temperature oxidation of nitrogen in the combustion air). Allowable NO_x standards are higher for engines where the rPR is greater than 25 (dimensionless). The NCE proposed standard does not have this higher allowance. The apparent assumption is that ways can be devised to limit either peak combustion temperatures and/or residence times in completely new designs. These NO_x standards are the primary point of contention in the current legislative review process.

The mass of emissions per thrust (grams/kilonewton in Table IV-3) is a composite calculation rather than an individual measurement.

The calculated parameters include emission measurements across the aircraft engine exhaust exit at various engine modes, fuel flows and thrust levels at various engine modes, and EPA time-in-mode factors to simulate the longest likely times for aircraft approach, landing, taxi-in, shutdown, start-up, taxi-out, take-off, and climb-out to 914 meters altitude.

A simpler set of aircraft engine regulatory emission levels shown in Table IV-4 were recently recommended by the International Civil Aviation Organization (ICAO, 1980a). They would not result in as great an emission reduction but would provide some controls for future engine emissions and would presumably make engine certification more predictable. They apply to the statistical mean of the engines certified rather than the upper limit intended by the EPA standards. The influence of this ICAO recommendation on the U.S. EPA aircraft emission standards under reconsideration remains to be seen.

Military aircraft engine emissions are not regulated by current or proposed EPA standards. The USAF and Navy have instead adopted "goals" to limit future engine emissions. Limitations for new engines qualified after 1981 are outlined in Figure IV-4 and fully described elsewhere (Blazowski and Henderson, 1974). These "goals" are intended to give guidance in the engine design phases where a compromise between many design parameters must be resolved. Environmental considerations are included but not at the expense of performance requirements. Engines which are built and fall short of these environmental goals will not necessarily be rejected unless the need to do so is indicated from air quality studies.

TABLE IV-4

ICAO REGULATORY LEVELS AND U.S. AIR FORCE/NAVY EMISSION GOALS

INTERNATIONAL CIVIL AVIATION ORGANIZATION RECOMMENDED REGULATORY LEVELS

HC: $\frac{Dp}{Foo} = 19.6$

CO: $\frac{Dp}{Foo} = 118$

NO_x: $\frac{Dp}{Foo} = 40 + 2\ \pi_{oo}$

SMOKE: $SN = 83.6\ Foo^{-0.274}$
(Not to Exceed SN = 50)

WHERE:
- Dp = Mass emission over aircraft landing and take-off cycle.
- Foo = Maximum thrust at take-off.
- π_{oo} = Maximum pressure ratio.
- SN = Measured smoke number.

US AIR FORCE/NAVY EMISSION GOALS
(For engines qualified after 1981;
Goals for 1979 not shown)

HC, CO:	Combustion efficiency greater than 99.5%	(engines with idle pressure ratio over 3/1)
	Combustion efficiency greater than 99%	(engines with idle pressure ratio less than 3/1)
NO_x:	Reduction of 50% from uncontrolled level at maximum thrust	(uncontrolled level is a function of combustion inlet temperature)
SMOKE:	Below visibility threshold	(the acceptable smoke number is a function of "nd" where n = number of engines in optical path; d = exhaust diameter)

CHAPTER V

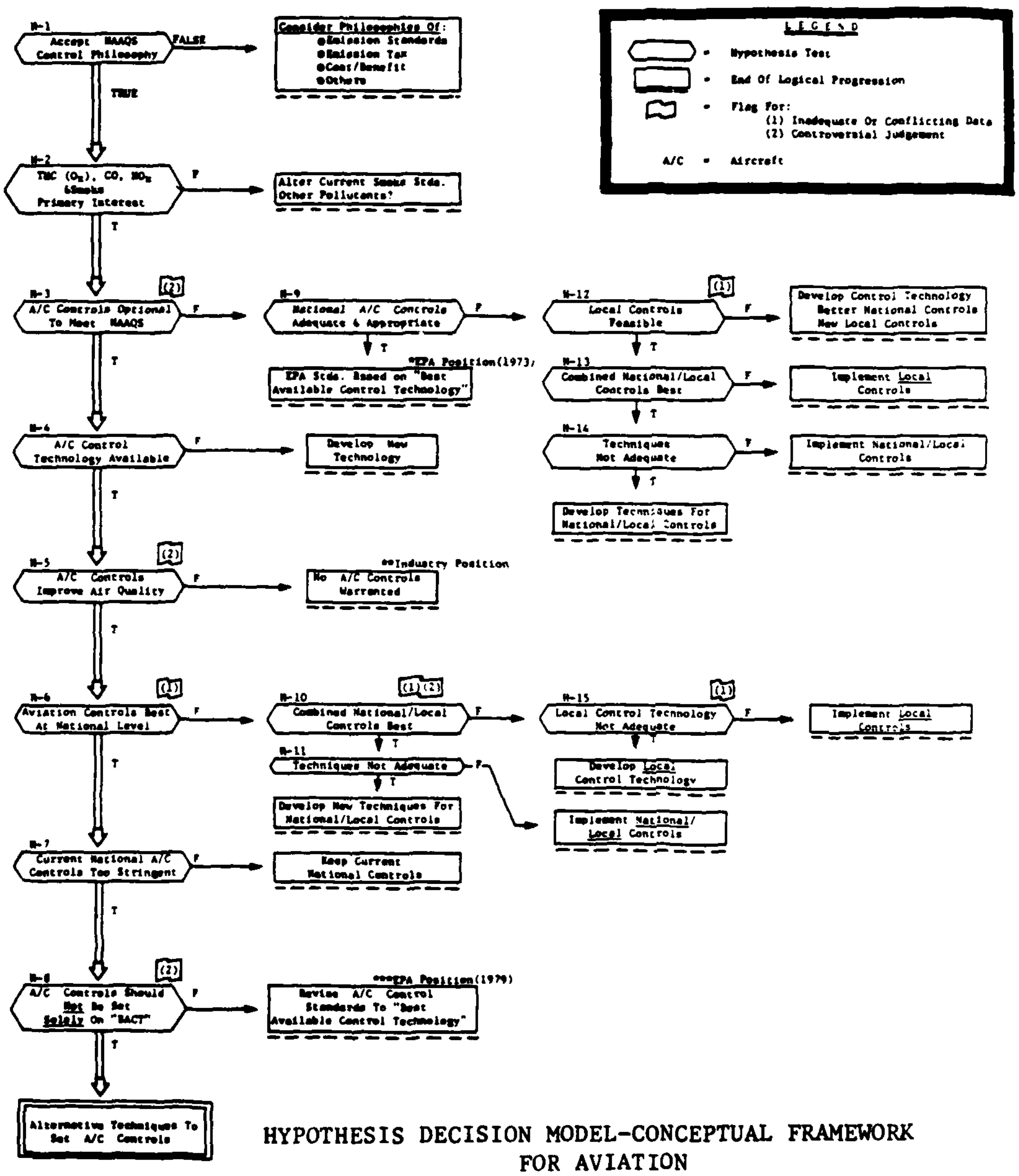
MODEL OF AVIATION STANDARD SETTING PROCESS

A model of the emission standard setting process is described in three related chapters. The initial concept of the model as intended for aviation sources is described in this chapter; application for THC (as a precursor to O_x formation), NO_x, CO and smoke emissions is in the next chapter; a generalization to non-aviation sources and a preliminary evaluation of the model are made in Chapter VII. An objective of the standard setting model is to show the inter-relationship of all key technical issues. It will also systematically lead to conclusions and recommendations which are essential to the setting of objective emission standards.

A basic premise in this study is that the optimum levels for aviation emission standards are not necessarily determined by judgements of the best available control technology for all pollutants. Decisions concerning the form and substance of optimum standards are guided by a logical framework subsequently termed the "hypothesis decision model". A schematic is shown in Figure V-1. Each of the major issues, worded as a test of hypothesis, are explained in Table V-1. This model is specifically designed for the aviation standard setting process but is also adaptable for other emission source categories. The value of this scheme is envisioned to be greatest for marginally important sources. These sources are large enough to be potentially significant yet small enough that the air quality benefits from potential controls are not easily determined.

FIGURE V-1 (Opposite Side)

CONTROL OF AIR POLLUTION FROM AVIATION: THE EMISSION STANDARD SETTING PROCESS



HYPOTHESIS DECISION MODEL-CONCEPTUAL FRAMEWORK FOR AVIATION

FIGURE V-1

TABLE V-1
EXPLANATION OF THE HYPOTHESIS DECISION MODEL

HYPOTHESIS	ISSUE	REMARKS
H-1: Accept the National Ambient Air Quality Standard (NAAQS) Control Philosophy.	-Not everyone agrees with the philosophy that air pollution control should be determined by using health and welfare effects data to set NAAQS levels to in-turn set emission control standards.	-A brief discussion of alternatives w be presented. -This hypothesis will be assumed to b true. It involves national policy is not peculiar to aviation issues. -The NAAQS levels will be assumed to accurate measures of health and we effect thresholds.
H-2: Hydrocarbon, oxidant, carbon monoxide, and oxide of nitrogen species plus smoke are the pollutants of primary interest for aviation standard setting.	-Odors as well as smoke from aviation have been the source of public complaints around airports. -Carcinogenic compounds present some undetermined risk.	-Visible smoke emissions from aircraf have already been drastically cont Current smoke emission standards a relatively non-controversial. -Odor complaints persist but remain a tractable problem for which no con *standards have been proposed.* -HC,CO, and NO_x controls are controve due to cost and justification.
H-3: Aircraft controls are optional (along with alternative strategies) to meet mandated NAAQS levels in general public exposure areas.	-EPA is required to limit aviation emissions if attainment of NAAQS levels is not otherwise possible.	-Even if aviation standards are not specifically required, they may be advisable so that all sources pay "fair share" toward environmental tection.
H-4: Aircraft control technology is available.	-Controls must be possible in the engineering sense and feasible from the safety standpoint for emission standards to be considered. If such technology is not available, further research is needed prior to setting *standards.*	-Considerable research has been done NASA, the Air Force, and aircraft companies. The technology for eng ing controls has been demonstrated the very high cost makes the advis of implementation questionable.
H-5: Aircraft controls improve air quality.	-Without reasonable evidence that air quality improvements will result from emission controls, there is little incentive to implement expensive control standards.	-The aviation industry has maintained that control standards would produ insignificant air quality benefits. -The "fair share" of pollution reduct which should be allocated to vari sources has yet to be defined.
H-6: Aviation controls are best implemented as uniform national standards.	-If air quality problems from aviation occur at only a few major airports, should controls be aimed at all engines used worldwide or at reduction of local emissions in problem areas?	-Aircraft towing or taxiing with fewe engines has long been advocated by some as an efficient way of reduci HC and CO emissions.
H-7: Current aircraft engine emission standards are too stringent.	-Relaxation of the EPA regulated limits and compliance deadlines has been petitioned by the aircraft engine companies.	-There is little disagreement that ch are necessary. -Changes from prior judgements of bes able control technology may be pre able to forcing difficult technolo improvements.
H-8: Aircraft controls should not be set solely on judgements of best available control technology.	-Standards at levels of best available control technology make sense if maximum controls with few economic constraints are warranted. -Where maximum controls are not required, other techniques which include air quality benefits and economic penalties may be preferable.	-Air quality and economic issues have viously been considered in an ind way but not in the setting of the latory limits. -Current national policy appears to b heading toward decisions which bal economic, energy, and environment considerations rather than maximu emission control.

TABLE V-1 (CONT'D.)
EXPLANATION OF THE HYPOTHESIS DECISION MODEL

HYPOTHESIS	ISSUE	REMARKS
H-9: National aircraft emission controls are adequate and appropriate.	-If engine controls are insufficient to meet NAAQS or if they are inappropriate, then other strategies must be devised.	-Aircraft towing in lieu of taxiing has long been proposed to supplement or replace HC and CO engine emission controls. -Other strategies involving airport and terminal design could be devised if warranted.
H-10: A combination of national/local controls are best.	-A combination of uniform national controls by engine redesign and localized controls may be preferable for: 1)greater emission control or; 2)less stringent national controls supplemented by localized controls when needed.	-Lower economic costs could result. -Energy and environmental benefits must be weighed against safety and economic concerns.
H-11: Techniques for implementation of national plus local controls are not adequate.	-Are further developments of combined national/local controls needed?	-A feasibility study, and airport demonstrations may be needed.
H-12: Local controls are feasible.	-Can adequate reductions of overall aviation emissions be reached with only localized control techniques?	-A feasibility study, airport demonstration and towing equipment development may be needed.
H-13: Combined national/local controls are best.	-Same issue as H-10 but reached from a different pathway.	-See H-10
H-14: Techniques for implementation of national plus local controls are not adequate.	-Same issue as H-11 but reached from a different pathway.	-See H-11
H-15: Local control technology is not adequate or has not been proven.	-The issue is whether or not the technology for localized emission reductions is adequate without the need for national engine emission standards.	-Additional development or testing of alternative localized control schemes may be required.

Numerous decision modules are illustrated in Figure V-1 in the form of hypothesis tests. Each hypothesis leads through alternative pathways to either other hypotheses or end of logical progression blocks. The end of progression blocks indicate specific actions or the start of another logical progression.

The proposed model contains hypotheses rather than elements to convey the idea that a true or false conclusion is the goal of each issue presented. While true or false outcomes may appear overly simplistic for the many complex issues presented, such determinations eventually have to be made and often dictate what actions must be taken by the regulatory agency. Determinations which are not clearly made by the scientific community will have to be inferred by regulators. Modifications to the decision model as conceived at the start of the evaluation are to be expected. While the pathways initially anticipated (null hypotheses) are the double lined "true" outcomes on the left column, other existing or new pathways could be pursued as this study progressed.

Public policy is formulated with multiple objectives which classically include economic efficiency, distribution of equity, public health and safety, and environmental quality. A general discussion of United States environmental policy is presented in Portney, et. al. (1978). The decision model in this work is considerably more narrow and focuses on the air quality objectives of environmental quality. Additional objectives are utilized in Hypothesis H-8 which includes economic considerations and in Hypotheses H-10 and H-11 which include economic and safety considerations. The hierarchy of multiple objectives (when appropriate) is:

(1) Aircraft passenger safety to be satisfied first.

(2) Environmental quality constraints as set by laws and regulations.

(3) Economic efficiency of alternatives.

For the hypotheses which include an economic efficiency objective, one would like to compare the marginal benefits and the marginal costs which result from alternative actions. Dec. ns could then be made so that the costs of control do not greatly exceed the damages from lack of control and vice versa. The theory and methodology for derivation of cost and benefit estimates have been described (Freeman, 1979a). Unfortunately only aggregate (i.e., not specific to any emission source type) benefits can usually be computed (Freeman, 1979b). Because of this difficulty, cost effectiveness ratios (cost per ton of pollutant emission reduction) are instead used as indicators of economic efficiency when compared to alternative actions.

Conclusions needed to determine a true or false outcome of hypotheses in this decision m are synthesized from an explicit consideration of all evidence relevant to the issue. These determinations are analogous to procedures used by the legal community when "common law" is synthesized by a careful weighing of all previous court holding. In fact, this model could prove useful to legally defend what and how all technical evidence has been considered. In the following chapter, this model is applied to issues involved in the standard setting process for the control of air pollution from aviation sources.

CHAPTER VI

APPLICATION OF HYPOTHESIS DECISION MODEL

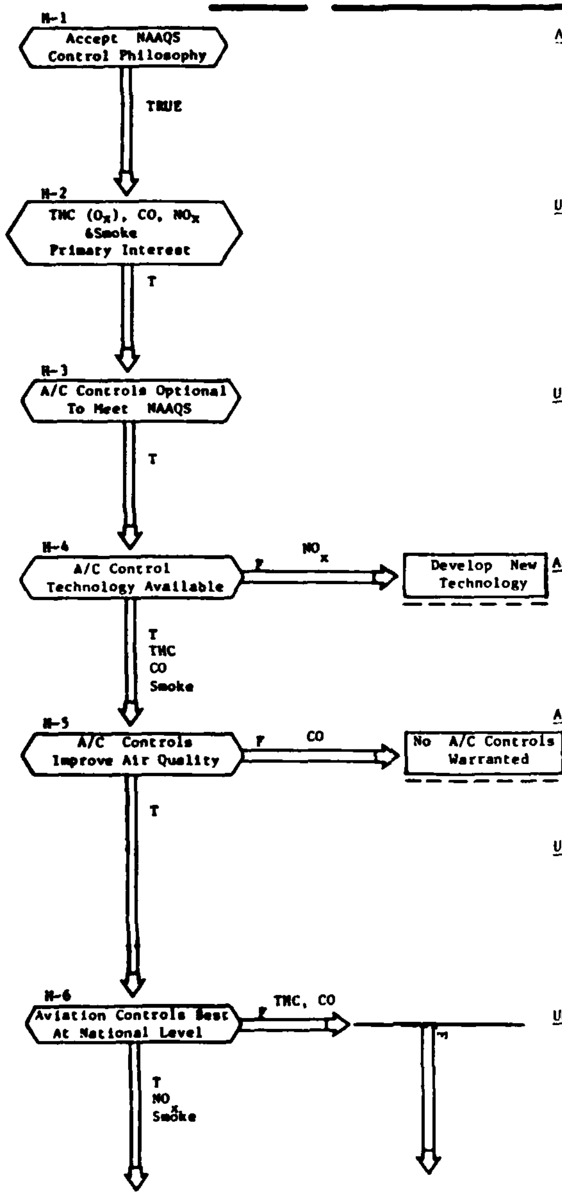
The hypothesis decision model illustrated in Figure V-1 was devised at the early stages of this investigation and served as a "road map" to suggest potential standard setting strategies. The remaining portions of this model after testing each hypothesis are shown in Figure VI-1. A summary description of each hypothesis is presented in this chapter. Full details of the evidence used to test each hypothesis are presented in Appendix A. The H-1 through H-11 labeling scheme is continued to permit cross-referencing between this figure and Appendix A. Readers can therefore scan the major technical issues and go to increased levels of detail (and therefore complexity) as desired.

Key assumptions and uncertainties are included in Figure VI-1 to help qualify the conclusions shown. Future changes in either the assumptions or uncertainties could also effect the conclusions. All conclusions after model application to aviation sources are summarized in this figure and are not repeated in this text. Elaboration of any of the issues or conclusions can readily be found in Appendix A. The effect of any single new study may not dramatically influence general conclusions unless it outweighs all the evidence or it changes the basic assumptions or uncertainties previously endorsed.

Application of the decision model involves many of the problems which are common in environmental sciences. The scientific data

FIGURE VI-1 (Opposite Side)

CONTROL OF AIR POLLUTION FROM AVIATION: THE EMISSION STANDARD SETTING PROCESS



H-1

Assumptions:
(1) Current U.S. air pollution control philosophy.
(2) NAAQS levels accurately reflect adverse effects.

Assumed "TRUE" (not tested):
Unlike the other hypotheses, H-1 is assumed to be true. The U.S. philosophy of air quality management emphasizes attainment of National Ambient Air Quality Standards (NAAQS) which are measures of adverse health or welfare effects. Emission standards are required for NAAQS attainment.
Alternative philosophies are described in Appendix A.1 but no attempt is made to judge their merits.

H-2

Uncertainties:
Carcinogenic compounds and hazardous materials from aircraft (and many other sources) are poorly understood.

Concluded "TRUE" with changes from Figure V-1:
The THC(O_x) designation is intended to show that aviation THC emissions are important due to potential contribution to ambient O_x levels.
NO_x and CO are of interest due to potential short term health effects.
Smoke is of interest for aesthetic reasons and tactical reasons (military aircraft only).
Odors are not included due to measurement difficulties which make engine emission standards unfeasible. Other potential pollutants are poorly understood.

H-3

Uncertainties:
(1) Relationship between O_3 NAAQS violations and specific emission sources such as aircraft.
(2) Conversion rate of aircraft NO to NO_2 -- important if a short term NO_2 NAAQS is promulgated.

Concluded "TRUE" based on all available evidence:
Aviation related emissions are not believed to cause NAAQS violations, even at areas next to airport boundaries. They are therefore a possible, (but not essential) source category which must be controlled to meet NAAQS levels. A "fair share" of emissions reduction can be allocated.

H-4

Assumption:
Technology shown to cause a 50% or greater emission reduction without extensive and high risk development is arbitrarily defined as "available".

Concluded "FALSE" for NO_x; "TRUE" for other pollutants:
Engine control technology is reviewed. Reductions of emissions from current production engines of 70-90% for THC and 50-70% for CO appear reasonable. Smoke emissions are now below "smokeless" criteria for most commercial aircraft.
NO_x control requires advanced combustor technology with extensive and high risk development.

H-5

Assumption:
The extensive ambient monitoring on airports and dispersion modelling of aircraft are adequate to identify a CO problem from aircraft if one exists.

Concluded "FALSE" for CO; "TRUE" for other pollutants:
Airport studies have not identified a CO problem due to aircraft. Controls would have a negligible effect on air quality.

Uncertainties:
Air quality effects from THC and NO_x emission controls occur downwind of airports and are highly dependent on local pollution conditions. Estimates of benefits from aviation controls have large uncertainties.

The limited photochemical studies of airports, emission comparisons, and failure to attain O_3 NAAQS levels in many areas of the country all seem to suggest that aviation THC and NO_x controls can be of value.

H-6

Uncertainties:
Few technical studies deal with the merits of uniform national controls versus local option controls.

Concluded "FALSE" for THC, CO; "TRUE for NO_x, Smoke:
Operational changes such as aircraft towing or reduced engine operation during taxi effectively reduce emissions and can be implemented on a local option basis. This could allow more relaxed, cost effective national aircraft engine emission standards or added emission reductions at airports in poor air quality areas.
NO_x and smoke emissions can only be effectively reduced with engine controls on a uniform national basis.

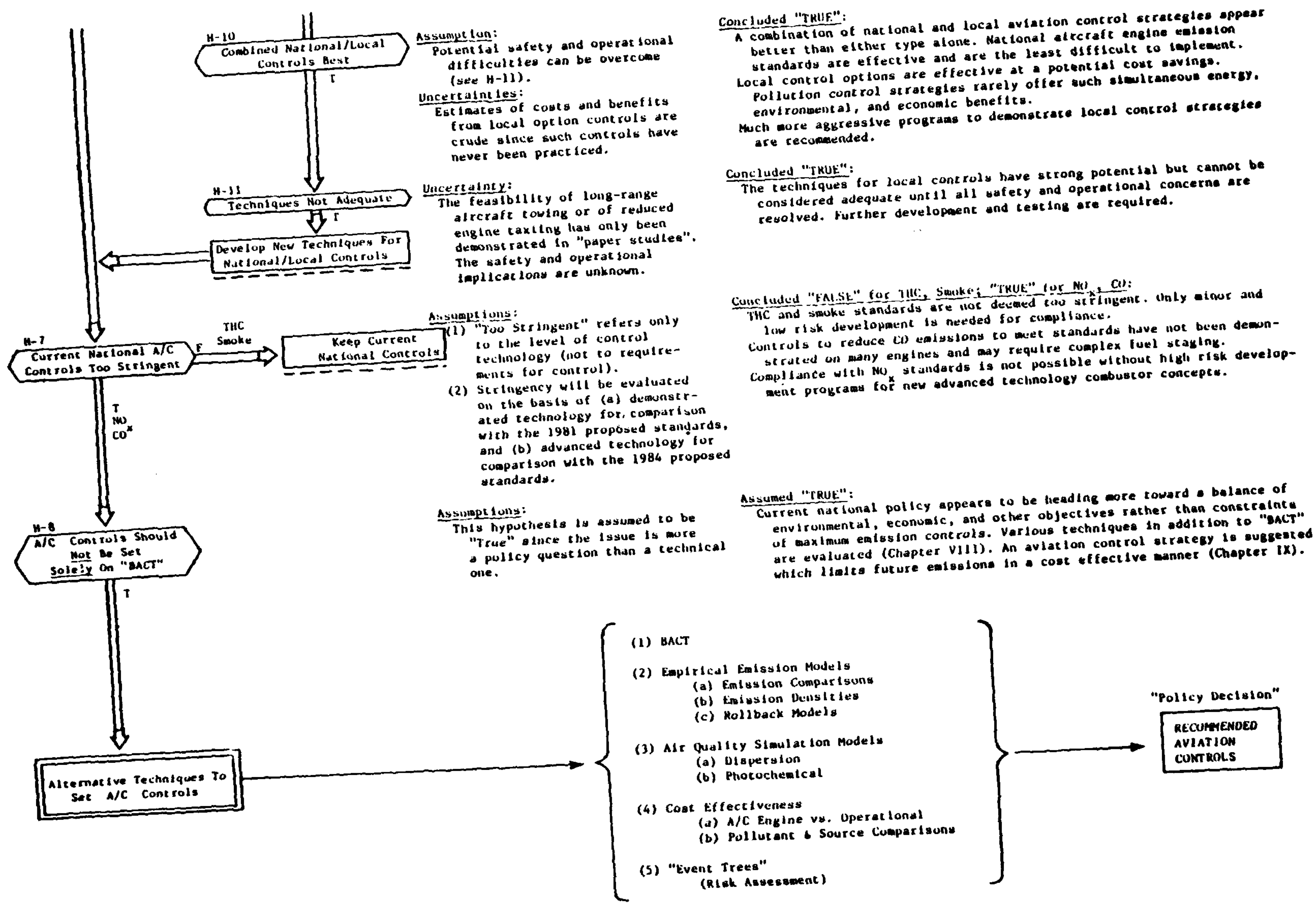


FIGURE VI-1 - HYPOTHESIS DECISION MODEL-RESULTS never seems adequate; studies often lead to contradictory conclusions where resolution of "correct" from "incorrect" is obscure; broadly worded hypotheses can only be tested with the available data which is invariably much narrower in scope; and technical uncertainties often diminish the credibility of an otherwise well executed analysis. Unfortunately, the process of setting environmental standards would be impossible if "good science" (95% confidence levels, consistent repeatibility, etc.) were demanded. The establishment of "good standards" depends on the careful collection of scientific data, weighing the data and formulating their implications, effective integration of the findings of many studies, and objective conclusions based on the best facts available. Re-evaluation of any standard is also important as more scientific data become available or as governmental policies change.

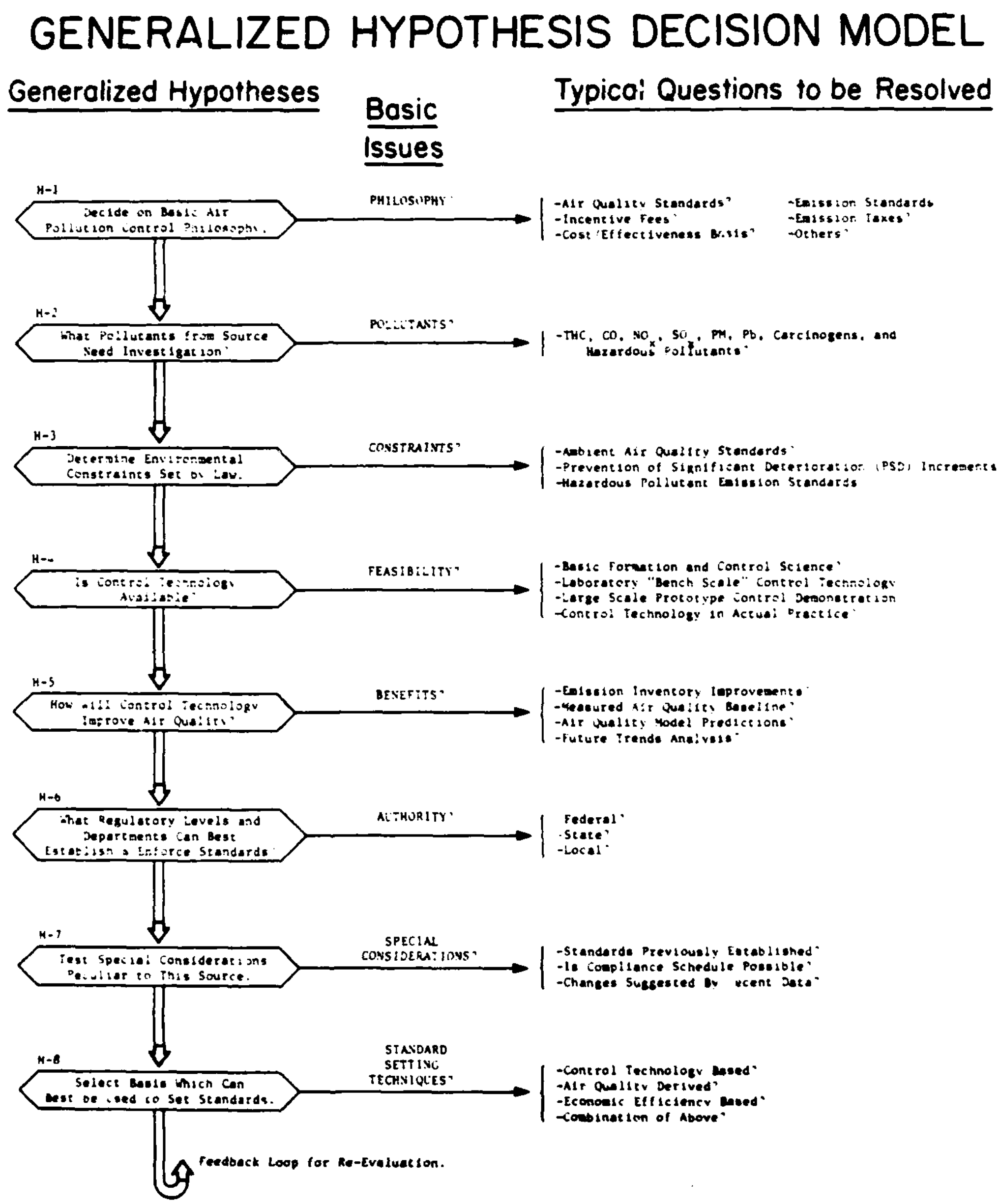
CHAPTER VII

EVALUATION OF THE HYPOTHESIS DECISION MODEL

While the prime thrust of this work is to develop and apply an emission standard setting model for aviation sources, the applicability of the model for other sources is also of interest. A generalized version of the model previously discussed is presented in this chapter. Both the strengths and weaknesses of this approach are evaluated. The model in this work is then discussed in perspective with other models and with the overall task of setting various types of environmental standards.

A. Generalization of Model

The hypothesis decision model developed in Chapter V and applied in Chapter VI is specifically tailored to address technical issues related to aviation sources. Different pollutants of interest, environmental constraints, availability of control technology, and regulatory levels can be expected for other source categories. However, considerable commonalities of technical issues also exist, independent of specific source categories. A generalized model based on these commonalities is shown in Figure VII-1. Comparison of this figure with Hypothesis H-1 through H-8 in Figure V-1 shows many similarities between the specific and general models. The general model can therefore serve as a conceptual framework to which additional technical decision modules would be added to adapt this approach to other source categories.



GENERALIZED HYPOTHESIS DECISION MODEL

FIGURE VII-1

B. Strengths and Weaknesses of Model

All approaches to setting environmental standards are bound to have both strengths and weaknesses. Environmental management is improved if both are well understood, irrespective of the approach used. A list of "Pros" and "Cons" concerning the general use of the hypothesis decision model is presented in Table VII-1. This list is based on personal observations and insights during development of this work. A more vigorous evaluation of the hypothesis model approach would be possible after application to a variety of sources (not just aviation-related ones), and by various researchers or policy-makers. The conceptualized strengths and weaknesses in Table VII-1 serve as a starting point for debate over the usefulness of this model.

All of the "Pro" arguments are believed to be real advantages which can be realized by application of the specific or general models. The advantage of having a graphical explanation of how specific control levels were established should be emphasized. This should enhance technical discussion during the review cycle, both internal and external to the government. It will also be valuable in any legal dispute to show the integration of many complex technical issues into the final rule-making. The appearance of arbitrary and capricious judgements in the setting of a standard by an administrative agency can more easily be averted.

Another important advantage is the careful documentation of decisions, assumptions, and uncertainties involved in setting the final emission standard. While the Freedom of Information Act allows access to all data available to the government agency, it doesn't

TABLE VII-1

"PRO" AND "CON" USE OF HYPOTHESIS DECISION MODEL
(Key words are underscored to emphasize most important concepts)

A. "Pro" Arguments for Use of Model	Discussion
1. Outlines a consistent plan used to set standard.	-Use of this model at the early stages of standard setting establishes a hierarchy of decisions to be made. Investigative efforts can initially be focused on the major decisions. Uncertainties which only affect minor decisions can be avoided or minimized.
2. Provides a graphical explanation of how standards were set.	-The applied model allows a first time reader to quickly grasp the issues and decisions which are involved in setting a particular standard. This framework promotes debate on detailed issues without losing sight of the basic objectives.
3. Establishes base for a legal defense of standards.	-Litigations regarding environmental standards and regulations seem to be the rule rather than the exception. Courts tend to overturn decisions of administrative agencies—not on technical judgement which courts are ill-prepared to second guess--but only when available evidence has not been considered. This model treats all data much in the way courts weigh evidence and is therefore valuable as a legal defense tool.
4. Breaks complex decisions into simpler discrete decisions.	-The standard setting process must invariably deal with many complex issues dealing with air quality impact, emission inventories, control technology, control costs, etc. This model permits discrete tasks to be done by different people or even subcontracted to different organizations. Results are easily integrated because of the model's framework.
5. Encourages technical conclusions to be made at the lowest possible level.	-There is currently great temptation for policy makers to pragmatically determine how strict a standard can be politically supported and then to ask their staffs to "technically justify" that level of control. This model would encourage technical conclusions by lower level personnel and based on all available evidence. Decisions can then be made by balancing political considerations but not by changing technical conclusions.
6. Documents the many decisions, assumptions and uncertainties which were in the standard setting process.	-Standards are rarely fixed for all time but are commonly re-evaluated at regular intervals or as new data becomes available. Documentation of decisions, key assumptions and technical uncertainties is therefore important at the time of re-evaluation. "Background documents" show how key decisions in the standard setting process were made.

TABLE VII-1 (Continued)

B. "Con" Arguments Against Use of Model	Discussion
1. The range of choice of administrators may be restricted.	-Upper level governmental administrators are acutely aware of public reactions to their standards. Well financed industrial lobbys typically hold positions far different from attention getting environmental action groups with administrators caught in the middle. Careful technical consideration and documentation of each decision within a complex standard may somewhat restrict the range of potential standards because increased scrutiny is possible.
2. Externalities (outside of air pollution objectives) are not considered in this model.	-Air pollution objectives are not the only consideration in a multi-objective society. Other important considerations, energy utilization and economic efficiency, for example, are not primary elements of this model. The governmental administrator still has the job of deciding what trade-offs with other public objectives must be made.
3. Additional "bureaucratic time and paperwork" may be perceived with the use of this model.	-Additional time to establish specific model hypotheses is required at the start of the standard setting process. This should be more than compensated for, however, by time saved from more understandable documentation, improved focus on issues of greatest impact, and from the integral framework useful in any legal defense.
4. Over-simplification of complex issues.	-Many scientific studies used as "evidence" in evaluation of each hypothesis took years of effort and cannot be condensed into the simplistic "true" or "false" outcomes of a hypothesis. An administrator must therefore accept on faith the technical judgements of his staff or whoever applied the model.

insure that such data is integrated into a comprehensible format or that judgements based on this data are documented. A more systematic documentation of all technical decisions also aids the regulatory agency who may need to re-evaluate an emission standard, perhaps years or decades after adoption when all key personnel have moved to other positions.

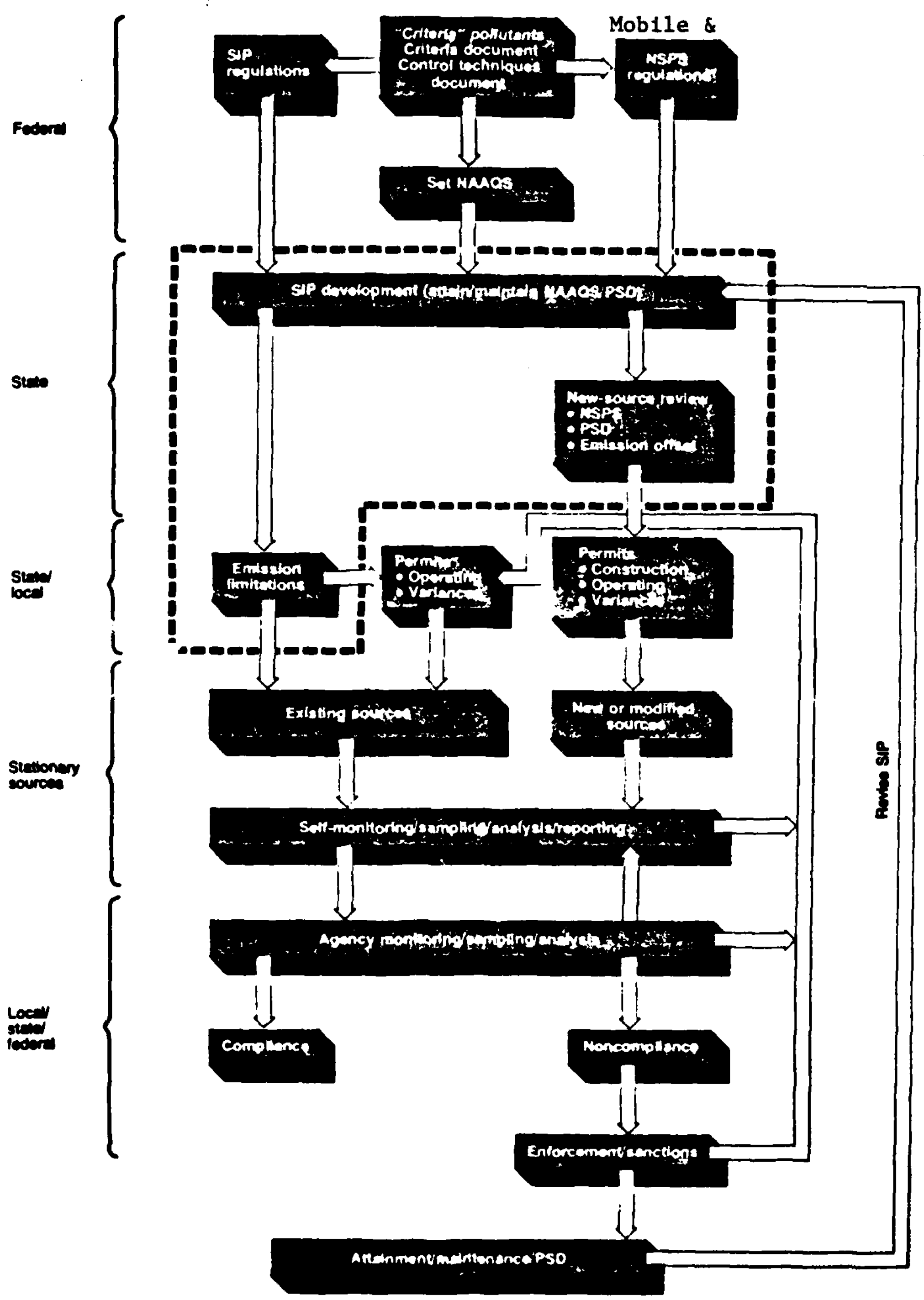
Some of the "Con" arguments in Table VII-1 may be more perceived than real. The amount of additional "bureaucratic time and paperwork", if any, remains to be seen. The development phase of specific standards may require additional time and effort to plan, classify all technical data, and integrate into the hypothesis model. Considerable time and effort is likely to be saved, however, in the public comment, implementation and legal defense phases associated with the emission standard. Approximately two man-years were spent in development and application of the hypothesis model for aviation sources. Ten years have elapsed since aircraft emission standards were first contemplated and enforceable standards have not been finalized. The speculation is made that a systems analysis approach to aviation emission standard setting, such as presented in the hypothesis decision model, may have saved rather than cost time and effort in the establishment of an enforceable emission standard.

Perhaps the strongest "Con" argument against use of the model is that externalities in the form of non-air pollution objectives are not considered in this model. The many potential externalities would be difficult to incorporate into any simple, generalized model. It could be argued that the use of a model with a single air pollution objective is unwise when many externalities are a real part of any emission standard setting process. This argument illustrates that even if the model is used and applied, it will never replace the need for competent administrative judgements and decisions to balance the positive and negative effects of such standards on society.

C. Model in Perspective

The hypothesis model represents a way to integrate all technical issues to aid the process of setting emission standards. It is therefore only a part of the overall task of air quality management. Discussion is now presented to put this model in perspective with other technical, procedural and policy models.

The major components of air quality management as practiced in the United States are illustrated in Figure VII-2. Note that responsibilities are split between various levels of government. There is no direct relationship between the NAAQS element and the Federal New Source Performance Standards (NSPS) or mobile source elements. Instead, an indirect relationship exists since the total effect of Federal controls plus other controls in the State Implementation Plans (SIPs) must be adequate to meet NAAQS levels. The peculiar situation exists where states must insure compliance with NAAQS levels which can be influenced by mobile sources. However, only Federal controls for new mobile emission sources are allowed under the Clean Air Act. The model in this work is directed toward the integration of technical issues in order to set emission standards low enough to allow states to attain the NAAQS levels by regulating sources under their control.



(SOURCE: Brady and Bower, 1981)

MAJOR ELEMENTS OF AIR QUALITY MANAGEMENT IN THE UNITED STATES

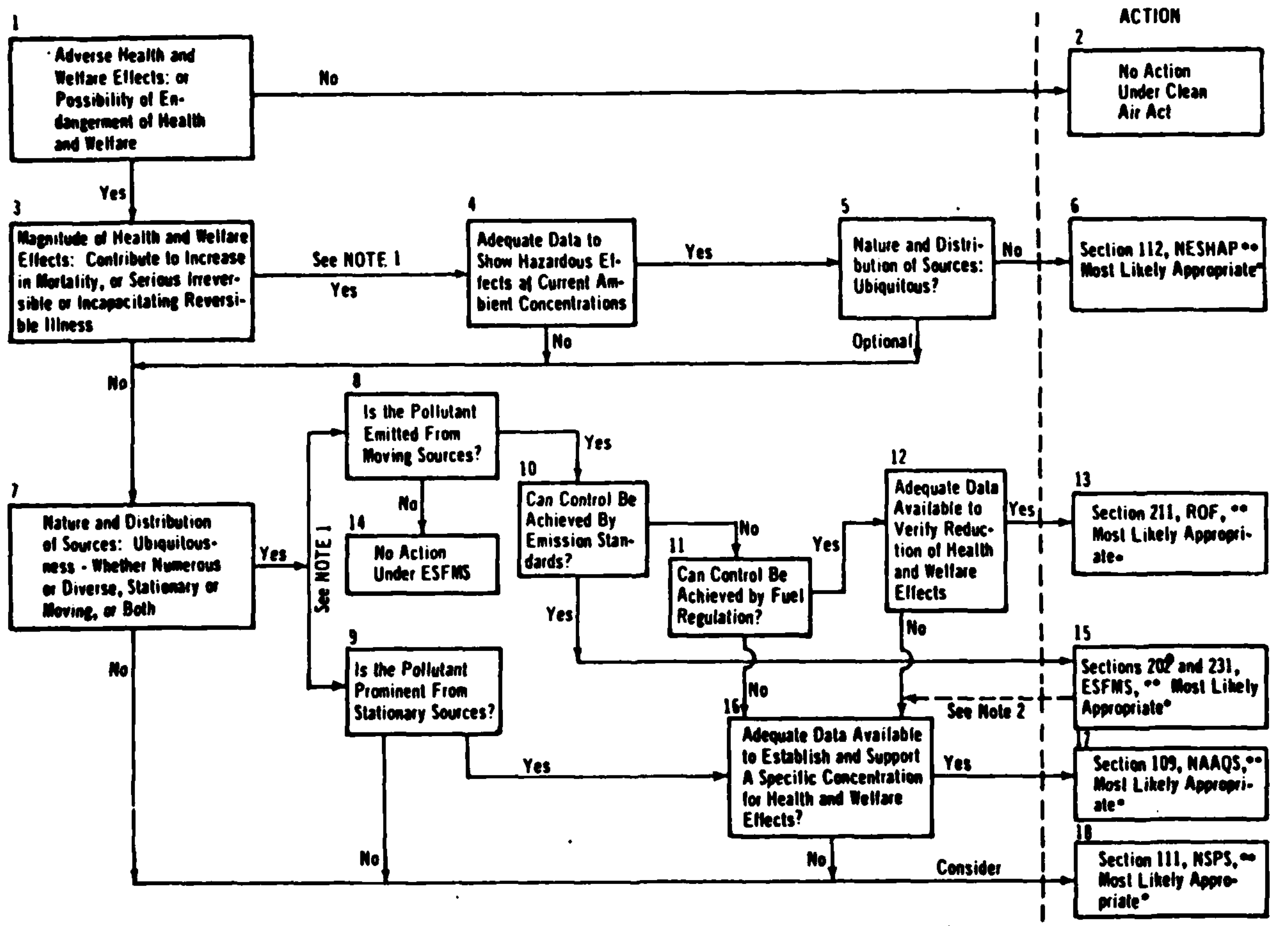
FIGURE VII-2

Numerous other models have been used for various purposes within the topic of air quality management. No attempt is made to present a comprehensive list or discussion of all models. In fact, the term "model" is used, or overused, to represent many kinds of technical, organizational, procedural, or political processes. Only a few such models are presented to illustrate the relationship between this work, other works, and the standard setting process within air quality management.

A guide for the determination of the type of regulatory action under the Clean Air Act is shown in Figure VII-3. This "Preferred Standards Path" was developed by EPA in 1977. It was used to determine that mobile source emission standards for polycyclic organic matter were not supported by the available technical data. A "yes" or "no" determination for each issue is sought much the same way as a "true" or "false" hypothesis outcome is sought in this work. Specific evidence used to weigh each issue is not presented in the application of this model (U.S. EPA, 1974).

Several procedural models for standard setting were found. The current procedures which EPA uses for writing regulations have been published (Federal Register, 1979a). The stages of development by the EPA lead office and review by various EPA working groups, steering committees, senior managers and the administrator are described. Procedures for external participation (public review and comment) on proposed regulations are also given.

The process for setting <u>ambient</u> air quality standards is shown



NOTE 1: A yes answer here simply means the pollutant is a candidate for regulatory action; however, it does not denote mandatory action.

NOTE 2: The dashed line indicates that significant pollution from stationary sources may remain even after utilizing ESFMS. Land use and transportation controls may need to be implemented in addition to Section 202.

*MOST LIKELY APPROPRIATE simply means that the indicated option may be the most logical without considering external factors. However, other ramifications may preclude its use. Also, more than one option (e.g., Sections 109 and 202; Sections 109 and 111; etc.) may be used in combination for any given pollutant in order to achieve the full intent of the Act. (Also see NOTES.) Section 111(d) is applicable to non-criteria pollutants. (SOURCE: U.S. EPA, 1974, p.A-4)

PREFERRED STANDARDS PATH: GUIDE FOR DETERMINATION OF REGULATORY ACTION

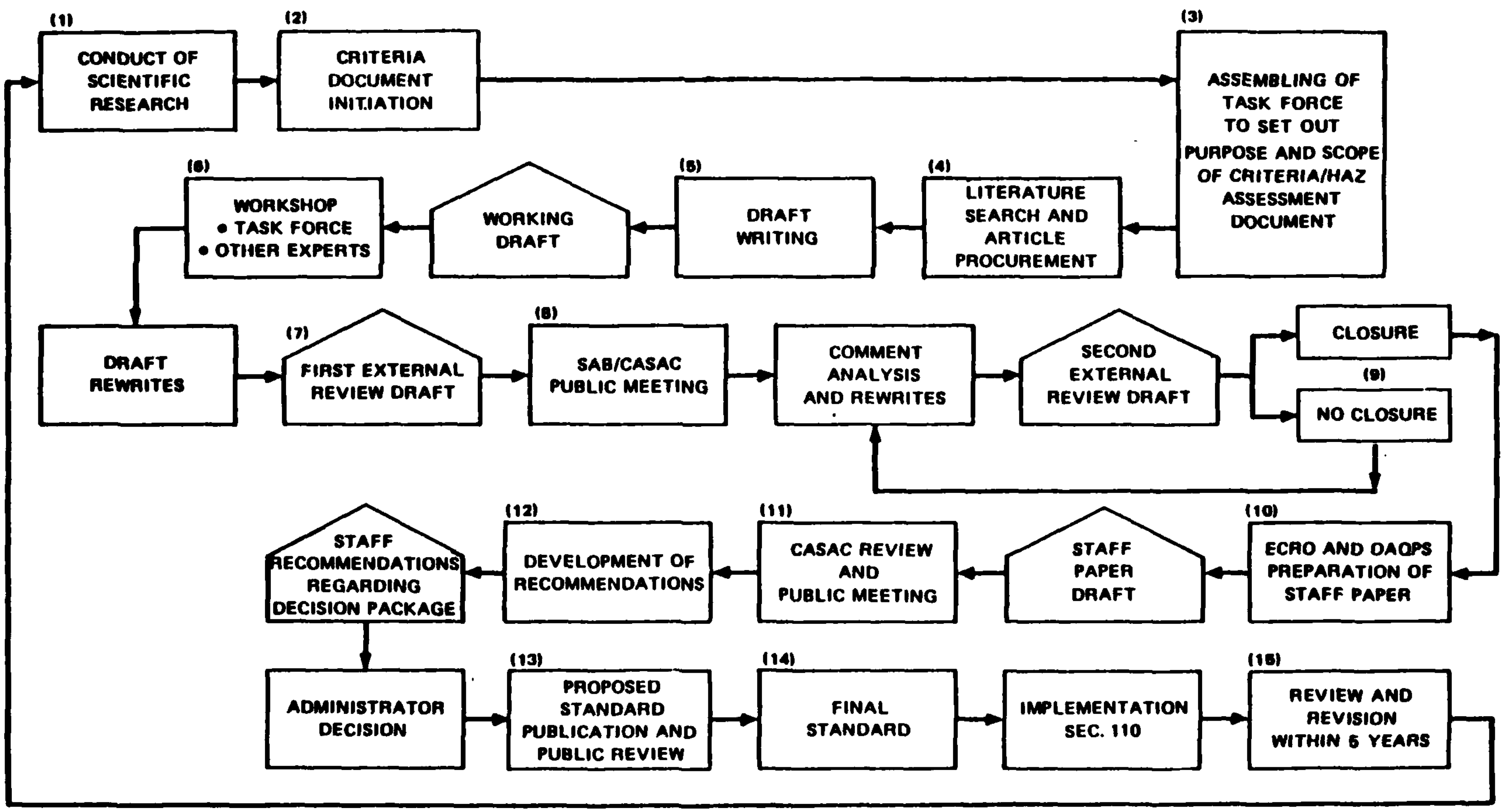
FIGURE VII-3

in Figure VII-4. This process involves many lengthy and complex steps from scientific research as published in the "Criteria Document" to the implementation and review of the final standards.

Another elaborate procedural model is represented by the Heuristic Model of Regulation Formulation (Schnare, 1978). This 21 step model consists of a series or flow of administrative events from the perception of an environmental problem through the publication of regulations to the solution of the problem. The model was used to analyze the National Interim Primary Drinking Water Regulations.

Several models which deal with technical issues in standard setting were found although none deal specifically with emission standards. Calabrese (1978) presents a simple conceptual model for deriving air and water quality standards. It is oriented toward translating biological or health effect data to acceptable exposure limits. The threshold limit concept is explained where an individual can be exposed to a particular dosage without an adverse health effect. This threshold concept is implicitly assumed in the NAAQS levels which are used in this work (Appendix A.1).

Quantitative risk assessments have been used in the 1979 revision to the ozone NAAQS. Risk assessment is the process of estimating the probability that an adverse health effect will occur at a given concentration or dosage. A framework to incorporate this technique into the setting of NAAQS levels for other pollutants has been proposed (Richmond, 1980). The National Commission on Air Quality recently recommended that EPA continue to refine and use the risk



(SOURCE: *U.S. EPA*, 1980 as presented by the *National Commission on Air Quality*, 1981)

NATIONAL AMBIENT AIR QUALITY STANDARD SETTING PROCESS
FIGURE VII-4

assessment methodology to set air quality standards and hazardous emission standards (NCAQ, 1981, p. 2.2-2). It should be one of many factors upon which EPA bases these standards.

An air quality standard setting model is presented in Atkisson and Gaines (1970). This model shows the flow of technical issues from public attitudes and air quality goals through the development of air quality standards. Mathematical models which attempt to relate ambient air quality levels which result from emission sources are described in this work and more generally in Stern (1976).

D. Usefulness of the Model in This Work

Costle (1980) simplified the entire air quality regulatory process into three sequential steps: (1) development of ambient air quality standards, (2) development of emission standards from the ambient standards, and (3) enforcement of the emission standards. The hypothesis decision model in this work focuses on the technical issues of step (2) of this regulatory process. While emphasis in development and use of this model is placed on aviation-related sources, a general version of the model is adaptable to other source categories.

There is no shortage of standard setting models as indicated by a review of just some of the available approaches. Many of these models describe organizational or procedural issues. The ones found for technical issues are concerned with the establishment of ambient but not emission standards. To the knowledge of this author, the emission standard model in this work is therefore not redundant of other models.

Potential benefits from the use of this model include the graphical explanations of complex issues which promote more effective communication, a framework to help prevent standards judged to be "arbitrary and capricious" in litigations, and a more thorough documentation of decisions based on technical assumptions and uncertainties in the derivation of specific emission standards.

The greatest disadvantage is that the output of this procedure is based almost entirely on air pollution objectives. Considerable skill and judgement is still needed to effect a balance with other social objectives. This model can be used alone or as an integral part of other models.

One of the summary recommendations by the National Academy of Sciences (NAS, 1977) after a lengthy review of EPA procedures is that:

> "EPA's decision on standards and regulations should be supported by analyses that explicitly state the objectives of the decisions, identify feasible alternatives, evaluate (quantitatively, to the extent possible) the consequences of each alternative decision, explore potential problems in implementation, and indicate and examine the degree of uncertainty about the effects of EPA actions. The analyses should be available to the public. Systematic and well documented analyses could substantially improve the quality of EPA decisions by providing a framework for discussion and for public understanding of the factors that enter the decision process. The analyses would make possible the generation and evaluation of a more complete set of regulatory alternatives".

The type of model presented in this work appears to have considerable potential as a response to this recommendation for more explicit support of EPA decisions on standards.

CHAPTER VIII

ALTERNATIVE STANDARD SETTING TECHNIQUES

All aircraft standards to date have been based on judgements of the best available control technology or perhaps even the best advanced control technology. Cost and other factors have been considered only in an indirect and non-explicit way. While this technique tends to minimize emissions of all pollutants, it also can lead to economic inefficiency where large efforts may produce minimal environmental benefits. Strict application of maximum emission control technology is increasingly being attacked by those trying to balance environmental, energy, and economic objectives. Various alternative techniques are therefore described in this chapter. These techniques include best available control technology, empirical emission models, air quality simulation models, cost effectiveness comparisons, and "event trees". Each will be described in a separate section followed by a comparative summary.

The techniques described in this chapter as alternative ways to derive emission standards are also the same techniques which are useful in analysis of the hypothesis decision model in Chapter VI and Appendix A. A cross-reference between each technique and each hypothesis is shown in Table VIII-1. Each of the techniques has strengths and weaknesses as pointed out in the sections below. Rather than base overall conclusions on any single technique, the results of all techniques are integrated at the end of this chapter.

A. Best Available Control Technology

The establishment of emission standards based on the maximum

TABLE VIII-1

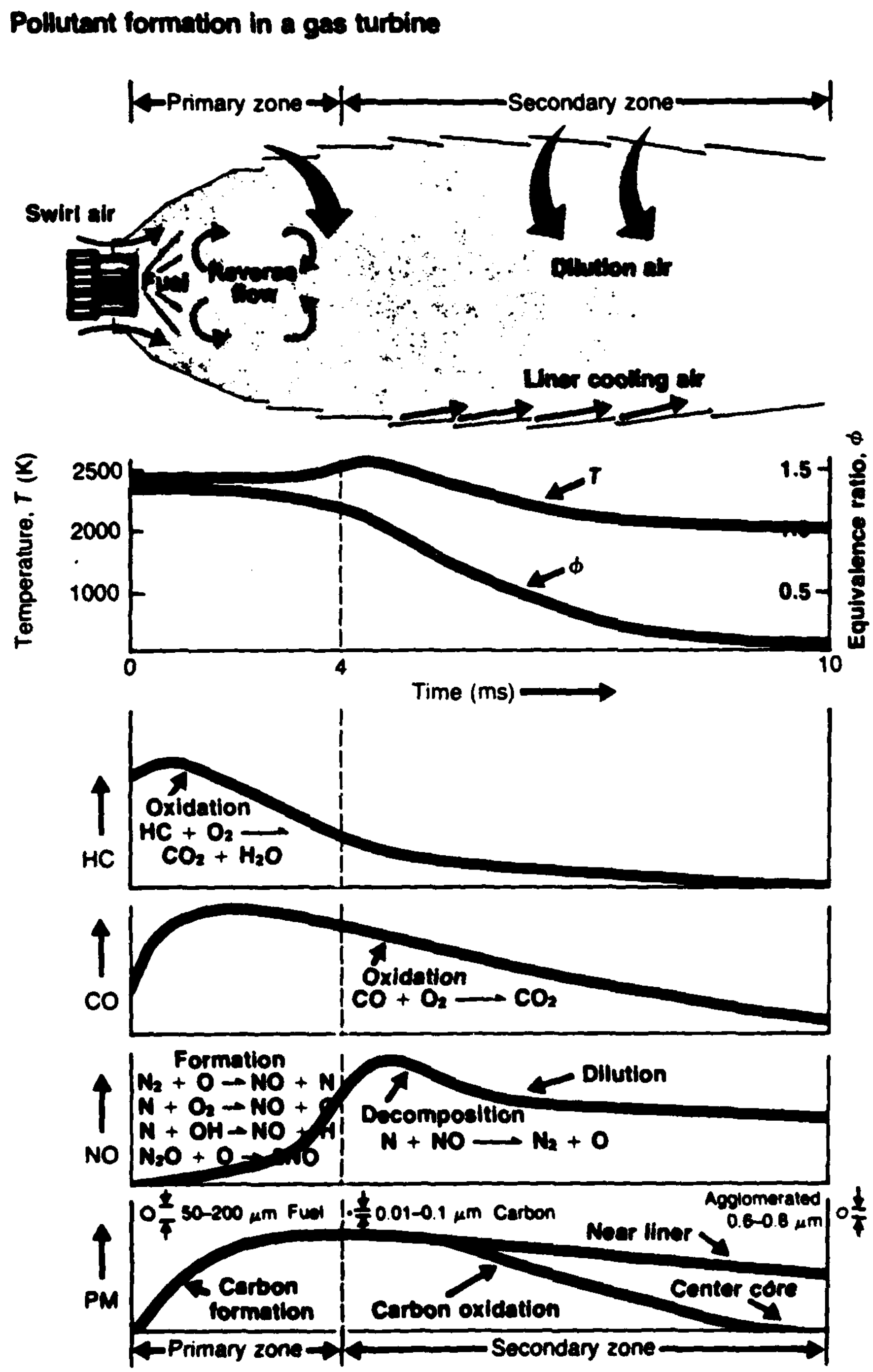
ALTERNATIVE TECHNIQUES USED IN THE HYPOTHESIS DECISION MODEL

Alternative Technique	Model Hypotheses (Shown in Figure V-1): 1	2	3	4	5	6	7	8*	10	11
1. Best Available Control Technology				x			x	x	x	x
2a. Emission Comparisons		x			x	x		x	x	
b. Emission Densities		x			x			x		
c. Emission Rollback Methods (based on ambient measurements)			x					x		
3a. Models: Dispersion		x	x		x	x		x		
b. Models: Photochemical			x		x			x		
4. Cost Effectiveness:										
a. Aviation Alternatives								x	x	
b. Pollutant & Source Comparisons								x		
5. "Event Trees"								x		

Null Hypotheses

*Includes data in both H-8 and Chapter VIII emission reductions technologically practicable is commonly done for many source categories. The strength of this technique is that maximum emissions control can theoretically be obtained. Also, difficult and controversial air quality assessments and cost/benefit (or cost effectiveness) studies can play a minimal role. The weaknesses of such technology based standards are that they can be economically inefficient or may not solve any real air pollution problems.

A basic understanding of the pollutant formation process is needed to appreciate the proposed technology based controls as well as their difficulties. A sketch of an aircraft engine combustor is in Figure VIII-1. Typical temperatures (T) and equivalence ratios (Ø) are shown. The equivalence ratio is the local fuel/air ratio divided by the stochiometric fuel/air ratio. The primary combustion zone is characterized by high temperatures and fuel rich conditions. Dilution air causes low temperatures and fuel lean conditions in the secondary zone. High THC concentrations in the combustor occur initially as the fuel vaporizes but then rapidly decrease. Carbon monoxide is formed in fuel rich conditions but can be substantially oxidized to CO_2. Nitric oxide (NO) levels are formed at high temperatures when sufficient oxygen is available and are typically "quenched" from decomposition by the cool secondary air flow. Particulate matter (PM) is formed when fuel droplets are inadequately vaporized prior to combustion. Oxidation of the carbonaceous particles proceeds unless "frozen" by low temperature air such as near the combustion liner (Heywood, et.al., 1971).



GAS TURBINE POLLUTANT FORMATION AND DECOMPOSITION

FIGURE VIII-1

The technology for control of aircraft engine emissions is detailed in other sources (Jones, et.al., 1978; Munt and Danielson, 1976; and Rudy, 1976). Some general approaches are outlined here as shown in Figure VIII-2. Additional details are presented in Appendices A.4 and A.7. The conventional technologies, effective for THC, CO and smoke, have been generally demonstrated but may require additional testing as dictated by the degree of control required. This technology is applicable to the proposed 1981 NME and 1985 IUE standards as described in the cost effectiveness section of this chapter. The advanced technologies, needed for any appreciable NO_x control, would require additional development, test and evaluation prior to implementation. They are required for the proposed 1984 NME standards. Emission controls are the prime motivation to implement advanced technology engines using current jet fuels. Potential improvements in thrust, fuel economy, or durability would not appear to warrant such complex new designs. A future switch to fuels from alternate energy sources such as shale-oil might necessitate these advanced technology concepts to maintain engine durability.

B. Empirical Emission Models

Three techniques are described which are based on the pollutant emissions from aviation sources. The relative simplicity of using and understanding these techniques is a definite advantage. They provide an understanding of the importance of various sources relative to each other. Difficulties occur, however, in attempts to relate emission controls (especially if on a uniform national basis such as aircraft engine standards) to air quality benefits (which are

CONVENTIONAL COMBUSTOR TECHNOLOGY (THC, CO Control at Idle)

FUEL SECTORING	Restrict Fuel to Portion of Combustor -Better Fuel Atomization -Higher Flame Temperature
ENRICH PRIMARY ZONE	Reduce Primary Airflow for Higher Flame Temperature
DELAY DILLUTION AIR	Promote CO Consumption
AIR BLAST	Use Venturi to Break-Up Fuel Droplets

ADVANCED COMBUSTOR TECHNOLOGY (NO_x, THC, CO Control)

STAGED FUEL INJECTION	Provide both Pilot and Main Stage Ignition -Higher Flame Temperature at Idle -Minimize Peak Temperatures at High Power
VARIABLE GEOMETRY	Optimize Airflow for Thrust Condition

SUMMARY OF AIRCRAFT ENGINE EMISSION CONTROL TECHNOLOGY

FIGURE VIII-2

typically local or regional in nature).

1. Emission Comparisons

Emissions from aircraft are a small part of all sources when considered on a national scale. As illustrated in Figure VIII-3, aircraft emissions account for about 1% for THC, NO_x, and CO (U.S. EPA, 1979). Particulate matter and SO_x are even less. Small general aviation type aircraft are the least important of the three aircraft categories shown and have recently been exempted from all aircraft engine emission standards (Federal Register, 1980). Commercial aircraft have lower THC but higher NO_x emissions than military aircraft due to a greater proportion of larger and newer engines.

Emissions on regional and local scales are also shown in this figure since identifiable health and welfare effects from air pollution generally occur on these scales. Aircraft contribute approximately 3% of all regional emissions. The region considered in this study includes ten counties for area sources and a grid extending a 12 mile distance from the Atlanta, Georgia airport for point sources (Cirillo, et.al., 1975). This contribution could increase, however, to about 6%-10% by 1990 as flight activity increases and stringent air pollution controls are applied to other sources. Aircraft related evaporative hydrocarbon fuel storage and transfer emissions may increase fourfold in the future due to additional fuel usage. A switch to alternative fuels with lower vapor pressures would lower this projected increase.

Aircraft are the dominant source category within the Atlanta airport boundary as shown in Figure VIII-3. Proposed control strategies have generally focused on aircraft engine emission

NATIONAL SCALE*

SOURCE	HC	NO_x	CO	PM	SO_x
ALL AIRCRAFT (%)	1.2	0.6	0.6	0.3	.08
-COMMERCIAL (%)	0.3	0.4	0.2	-	.03
-MILITARY (%)	0.7	0.2	0.2	0.3	.05
-GENERAL AVIATION (%)	0.2	-	0.2	-	-
ALL SOURCES (1000 Tons/Yr)	30,000	22,000	116,000	36,000	33,000

REGIONAL SCALE**

ATLANTA REGION OF 10 COUNTIES

SOURCE	HC 1973	HC 1990	NO_x 1973	NO_x 1990	CO 1973	CO 1990
AIRCRAFT (%)	3.2	6.2	3.1	7.2	2.4	10.3
FUEL LOSS (%)	0.8	4.0	-	-	-	-
ATLANTA REGION (1000 Tons/Yr)	89	88	75	92	300	156

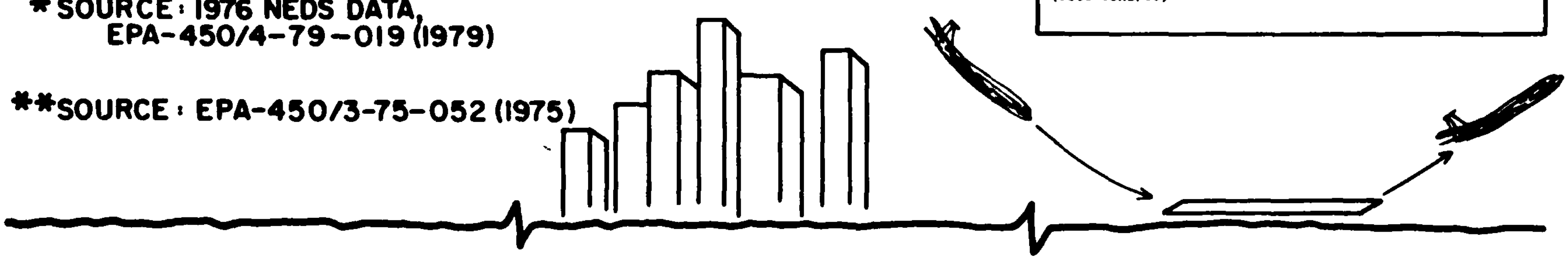
AIRPORT BOUNDARY**

ATLANTA AIRPORT

SOURCE	HC	NO_x	CO
AIRCRAFT (%)	69	78	58
FUEL LOSS (%)	11	-	-
TRAFFIC, MISC (%)	20	22	42
TOTAL AIRPORT (1000 Tons/Yr)	3.9	2.9	9.5

*SOURCE: 1976 NEDS DATA, EPA-450/4-79-019 (1979)

**SOURCE: EPA-450/3-75-052 (1975)



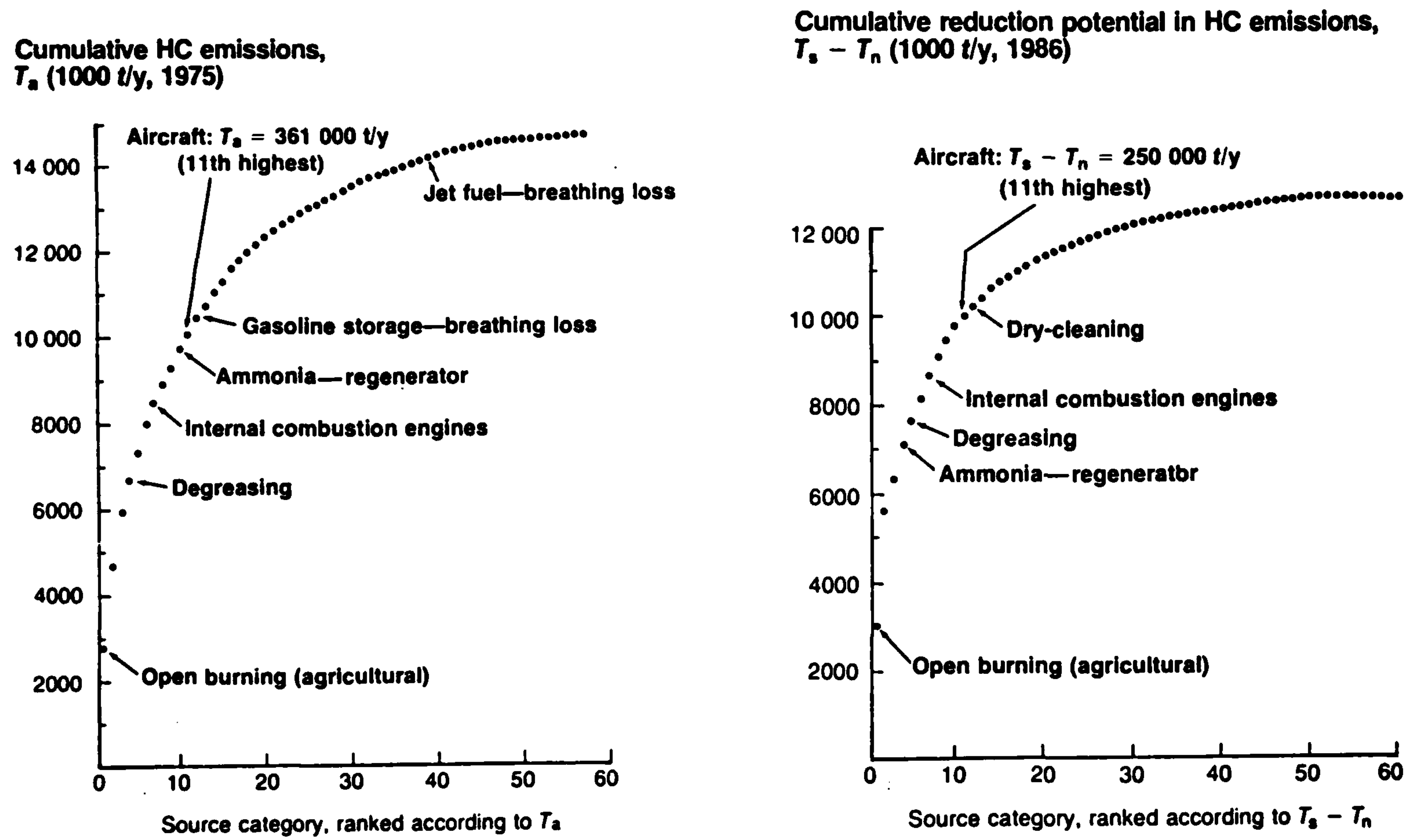
AIRCRAFT CONTRIBUTION TO NATIONAL, REGIONAL, AND AIRPORT EMISSIONS

FIGURE VIII-3

reductions rather than other airport sources. Emissions data as shown are not always representative of air quality effects, however. Aircraft emissions are distributed throughout much of the airport and are subject to considerable atmospheric dilution. In contrast, emissions from automobile traffic are often concentrated in congested terminal areas with reduced potential for atmospheric mixing. Recent measurements of CO inside and outside of a congested airport terminal area were less than levels associated with health implications but further studies may be necessary (Bellin and Spengler, 1980).

Emission studies as presented are a good starting point but have other serious shortcomings. The national emissions data are subject to inaccuracies due to the large number of sources and calculations involved in the EPA's National Emission Data System (NEDS). This is especially true for aircraft where the translation of recent emission factor data over the many operational modes and many different airport situations can be a complex task. Regional differences in emissions are bound to occur. The 3% contribution of the Atlanta airport to regional emissions in Figure VIII-3 appears to be higher than in most regions which are 1% or less (Jordan, 1977).

Another way to suggest the severity of aircraft as an air pollution source is by comparison with other source categories. Aircraft THC emissions are plotted in Figure VIII-4 along with the highest 60 source categories for which EPA is considering additional New Source Performance Standards (U.S. EPA, 1977a). The 27 sources for which NSPS have already been promulgated are not shown. Such



COMPARISON OF NATIONAL AIRCRAFT EMISSIONS WITH "MAJOR" STATIONARY SOURCES
FIGURE VIII-4

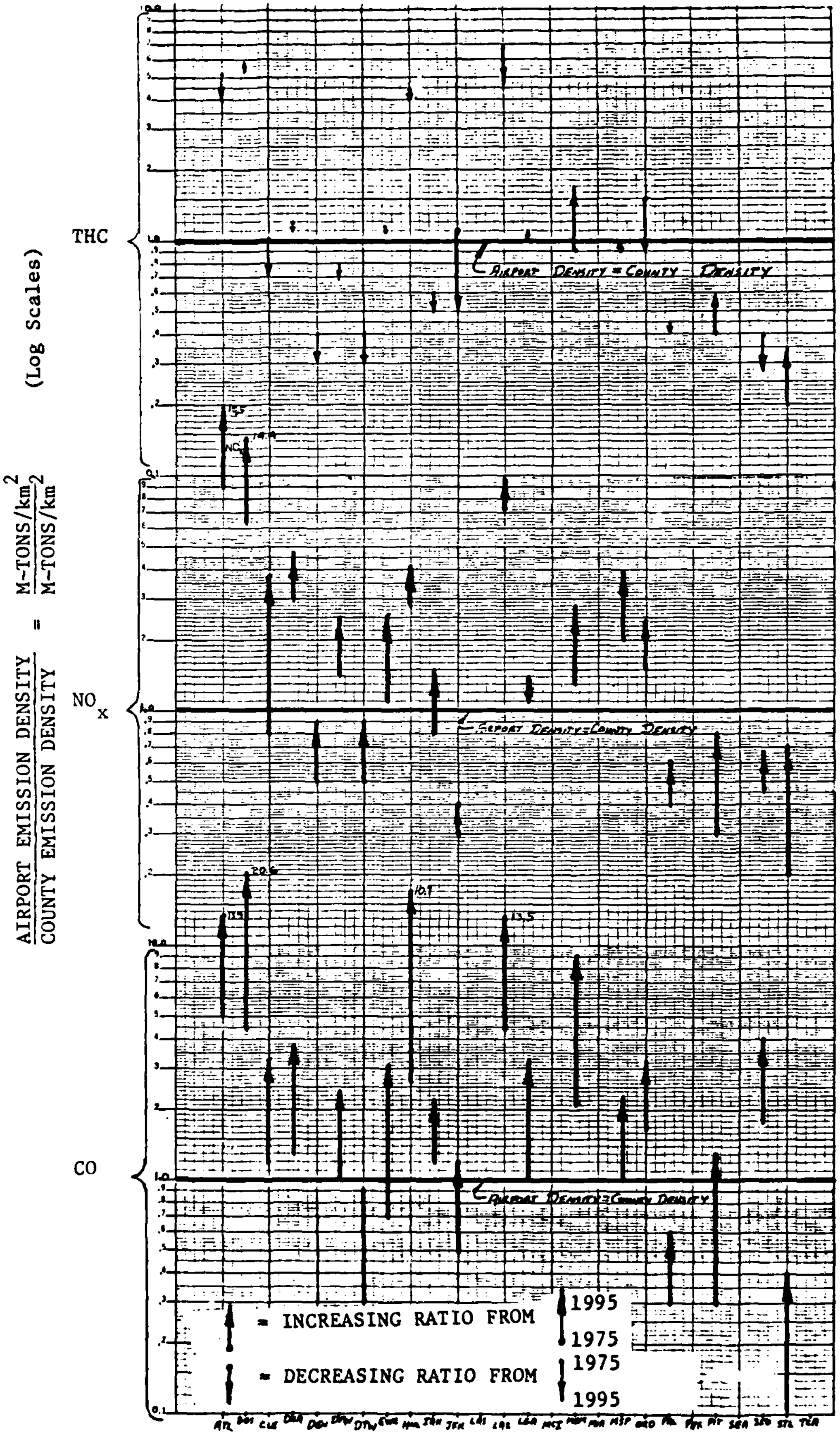
comparisons are not frequently made since aircraft are regulated in a different part of the Federal Clean Air Act and by different offices within EPA. Aircraft rank as the eleventh highest category both when comparing annual emissions (Ta) and emissions reduction potential (T_s - T_n). Aircraft emissions between cities are not included -- only those from aircraft landing and takeoff cycles in the airport vicinity. The T_s - T_n parameter represents annual emissions which can be reduced from levels with only current control standards (T_s) to levels projected with new or hypothesized control standards (T_n). A 70% THC control averaged over all aircraft is assumed. There are strong pressures for EPA to regulate all THC sources possible since the oxidant ambient air quality standard cannot be met until at least 1987 and then only with a 46% reduction in emissions from the 1977 level (CEQ, 1979). This reduction requires strict vehicular emission control standards, automotive inspection and maintenance programs, and vigorous NSPS programs. The aircraft emission reduction potential represents 2% of the 46% THC reduction which is needed nation-wide. The number of stationary sources for which NSPS will ultimately be promulgated remains to be seen but could include many or even most of the sources represented in this figure.

2. Emission Densities

Emission densities offer another relatively simple way of comparing airport to non-airport emissions. Since emissions are normalized by land area, the resulting ratio can suggest if a source causes "hot spots" within an area of air pollution concern. Strategies can be devised so that emphasis is given to sources which cause higher emission densities. An obvious shortcoming of such a technique is that source dispersion inducing mechanisms such as stacks or exhaust velocity turbulence are completely ignored. Nevertheless, some useful information can be gained from emission densities.

The FAA Airport Emissions Data Base is believed to be the best source of airport emission densities. Direct output options include the densities (tons of pollutant/km^2) of airports, counties, and air quality control regions (AQCR) in which the airports are located. Densities are output for each of the 26 largest commercial airports and 13 general aviation airports. The county and AQCR information were provided for use in this data base by the EPA Office of Air Quality Planning and Standards from the EPA National Environmental Data System (NEDS).

In order to show general relationships over a wide range of airports in different emission surroundings, a novel data reduction scheme is employed (Figure VIII-5). The THC, NO_x, and CO airport to county ratios are shown for 20 of the 26 largest commercial airports. Data for individual airports and counties are included in Appendix B. The 6 airports not graphed were omitted because the county emissions data were suspect. Airport to county emission density ratios are actually a ratio of ratios (airport emission density in tons of pollutant per square kilometer divided by the county emission density in the same units). A normalized dimensionless number results and is an indicator of airport pollution relative to its surroundings. Emissions computed for 1975 as well as those projected for 1995 are used. No aviation emission controls are assumed.



COMPARISON OF AIRPORT TO COUNTY EMISSION DENSITIES
FIGURE VIII-5

Several observations can be made from Figure VIII-5. First, airport densities are typically higher than their counties for CO and NO_x , but less often for THC. The high airport THC densities at Atlanta, Boston, Honolulu and Los Angeles are offset by low densities at Denver, Detroit, San Francisco and St. Louis. Airport NO_x and CO densities substantially exceed those of the counties at Atlanta, Boston, Honolulu, Los Angeles and Memphis. While aircraft engines are the largest component, airport emissions also include automobiles, aircraft auxiliary power units, service vehicles, refueling losses, and miscellaneous point sources.

A second observation is that without emission controls, airports will become more important as future NO_x and CO sources, relative to county emissions. One reason is that between 1975 and 1995 airport activities are projected to increase. Also, during the same period, county emissions are projected to be reduced as stringent control regulations are implemented. Airport CO emissions also have a much higher component due to automobiles than in the THC and NO_x categories. The airport/county densities for THC drop at many airports due to modest improvements with newer aircraft engines even without mandated controls.

3. Rollback Models

Rollback models can suggest levels for emission standards if measured ambient air quality levels in excess of standards can be related to particular source categories. For example, if a copper smelter causes measured SO_2 levels of 50% above the short-term NAAQS, a control level of 50% would be suggested as a first approximation. The bulk of the evidence presented in Appendix A.3 leads to the conclusion that aircraft and airports do not independently cause any NAAQS violations (although they could be undefined contributors to such violations). Rollback computations were therefore not appropriate in this work.

C. Air Quality Simulation Models

Both dispersion and photochemical models were used in many of the hypothesis model tests as previously indicated in Table VIII-1. Both techniques provide important insights into the relationship between pollutant emissions and the resultant ambient air quality concentrations. However, from the regulatory viewpoint, both suffer from the great complexity needed to accurately characterize the physics of aircraft plume behavior in the atmosphere or the chemistry of the emissions when mixed in photochemical reactive atmospheres. The more complex models should theoretically produce better results but the accuracy is difficult to determine.

1. Dispersion Models

Extensive aircraft/airport dispersion model and ambient monitoring studies since 1973 have not suggested that CO problems exist downwind from any airport in the United States. High CO levels suggested in studies prior to 1973 appear to be from over-simplified or incorrect dispersion model applications combined with high ambient measurements influenced by non-aircraft sources. Standards for control of CO emissions from aircraft do not appear to be justified from dispersion model (and ambient monitoring) results.

The long term dispersion models indicate that annual NO_x concentrations due to airports are well below the annual NO_2 NAAQS. This is true even if 100% of the NO_x is assumed to be instantaneously converted to NO_2.

2. Photochemical Studies

Emissions of THC are not known to be a direct health problem. Thus participation of airport related THC as a precursor to O_3 concentrations in excess of health derived ambient standards need to be defined. This is a difficult task since peak O_3 concentration are likely to occur some distance from the airport and are the product of many emission sources, local mixing (dilution), and incident solar radiation. Several techniques and studies, none of which are scientifically convincing at present, are reviewed in this section. Also, the role of airport NO_x emissions as related to a proposed short-term NO_2 ambient standard is discussed.

Most of the hydrocarbon species within the THC category of aircraft engine emissions can be classified as photochemically reactive. Groth and Robertson (1975) conducted a measurement study with three different aircraft engines (JT4, JT3D, JT9D) and two different fuels (JP5 and Jet A). Their unreactive component consisted of paraffins while the reactive component included olefins, aromatics, and oxygenated hydrocarbon derivatives. Over 70% of all hydrocarbons were reactive during engine idle conditions and increased to essentially 100% at high power conditions.

The usefulness of detailed reactivity schemes were investigated by Trijonis and Arledge (1976). All organic source emissions in metropolitan Los Angeles were separated by chemical species into reactivity classes. Class I (least reactive) through Class V (most reactive) are shown in Table VIII-2 for turbine aircraft engines. Note that 33% of the emissions are in Class VI, 38% in Class III, and only 9% are in the low reactivity Class I.

TABLE VIII-2
ORGANIC EMISSIONS FROM GAS TURBINE ENGINES

MOLE %

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	7	Mono-tert-alkyl benzenes	4	C_{4+}-paraffins	38	Prim-& sec-alkyl benzenes	8	Aliphatic olefins	19
Acetylene	1	Cyclic ketones		Cycloparaffins		Dialkyl benzenes	8	α-methyl styrene	
Benzene	1	Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	10
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl benzenes	4
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									
TOTAL CLASS I	9 %	TOTAL CLASS II	4 %	TOTAL CLASS III	38 %	TOTAL CLASS IV	16 %	TOTAL CLASS V	33 %

(SOURCE: Trijonis and Arledge, 1976)

These six classes were then combined using 2-group, 5-group, and 6-group reactivity classifications. The reactivity of automobile exhaust was defined as 0.72 in each classification. Results are shown in Table VIII-3. The jet aircraft emissions are relatively more reactive than automotive exhaust on a molar basis but less reactive on a weight basis. Jet aircraft accounted for 0.6% of all reactive emissions while piston aircraft accounted for 1.2%. Based on four empirical/aerometric models and two smog chamber models, Trijonis concluded (from a 1972 baseline) a 90% or greater level of control of all THC emission sources is needed to meet the NAAQS for O_3. (This standard has since been relaxed from 0.08 to 0.12 ppm.) Accounting for the relative reactivity of emissions only drops the "fair share" of jet aircraft controls from 90% to 85%. The overall report conclusion was that very stringent THC controls should be applied to virtually all sources in the Los Angeles region. Only PCE dry cleaning and 1,1,1-T degreasing should be excluded from control requirements due to their low reactivity.

Two other studies have been found which deal specifically with the oxidant producing potential of aircraft. A brief description of each is given in Table A-4. Unfortunately, due to the outdated chemical mechanism used in one (Whitten and Hogo, 1976) and the ambiguous results of the other (Duewer and Walton, 1978), little can be concluded from these works which aid in the setting of aviation emission standards.

The short-term NO_2 concentrations due to airports are also of interest. Recent work by Yamartino and Rote (1979) suggested that ambient NO_2 levels downwind of airports could be in the range of

TABLE VIII-3

THE REACTIVITY OF AIRCRAFT COMPARED WITH OTHER EMISSION SOURCES

SOURCE CATEGORY	SOURCE MOLAR REACTIVITIES			SOURCE WEIGHT REACTIVITIES			REACTIVE EMISSIONS					
							REACTIVE TONS/DAY*			PERCENT OF TOTAL		
	2-GROUP SCHEME	5-GROUP SCHEME	6-GROUP SCHEME	2-GROUP SCHEME	5-GROUP SCHEME	6-GROUP SCHEME	2-GROUP SCHEME	5-GROUP SCHEME	6-GROUP SCHEME	2-GROUP SCHEME	5-GROUP SCHEME	6-GROUP SCHEME
STATIONARY SOURCES: ORGANIC FUELS AND COMBUSTION												
Petroleum Production and Refining												
Petroleum Production	.16	19	.12	.38	.45	.29	24	28	18	1.4	1.7	1.1
Petroleum Refining	.89	.71	.71	.66	.53	.53	33	27	27	1.9	1.6	1.6
Gasoline Marketing												
Underground Service Station Tanks	.82	.71	.71	.98	.84	.84	47	40	40	2.7	2.4	2.4
Auto Tank Filling	.96	.78	.79	.90	.73	.74	94	78	77	5.4	4.6	4.7
Fuel Combustion	.10	.20	12	.28	.55	.33	6	13	8	0.3	0.8	0.5
Waste Burning & Fires	.26	37	32	.54	77	.67	22	32	27	1.3	1.9	1.6
STATIONARY SOURCES-ORGANIC CHEMICALS												
Surface Coating												
Heat Treated	.80	.70	.70	.67	.59	59	9	8	8	0.5	0.5	0.5
Air Dried	.86	.69	.69	.68	.55	.55	88	71	71	5.0	4.3	4.3
Dry Cleaning												
Petroleum Based Solvent	1.00	.66	66	.55	.36	.36	9	6	6	0.5	0.4	0.4
Synthetic Solvent (PCE)	00	.10	.10	.00	.04	.04	0	1	1	0.0	0.1	0.1
Degreasing												
TCE Solvent	1.30	.95	.95	.52	.50	.50	6	5	5	0.3	0.3	0.3
1,1,1-T Solvent	00	.10	.10	.00	.05	.05	0	5	5	0.0	0.3	0.3
Printing												
Rotogravure	.84	.62	.62	.69	.52	.52	21	16	16	1.2	1.0	1.0
Flexigraphic	.81	.76	.76	.98	.92	.92	15	14	14	0.9	0.8	0.9
Industrial Process Sources												
Rubber & Plastic Manf.	.84	.97	.98	.79	.92	.93	33	39	39	1.9	2.3	2.4
Pharmaceutical Manf	66	64	.64	61	.59	.59	10	9	9	0.6	0.5	0.5
Miscellaneous Operations	56	53	53	.48	.46	.46	40	38	38	2.3	2.3	2.3
MOBILE SOURCES												
Gasoline Powered Vehicles												
Light Duty Vehicles												
Exhaust Emissions	.72	.72	.72	.72	.72	.72	562	562	562	32.1	33.9	34.2
Evaporative Emissions	95	80	.80	.72	.61	.1	346	293	293	19.8	17.7	17.9
Heavy Duty Vehicles												
Exhaust Emissions	.72	72	.72	72	72	.72	205	206	208	11.7	12.3	12.5
Evaporative Emissions	.95	.80	.80	.72	.61	.61	48	41	41	2.7	2.5	2.5
Other Gasoline Powered Equipment												
Exhaust Emissions	.72	.72	.72	.72	.72	.72	79	79	79	4.5	4.8	4.8
Evaporative Emissions	.95	.80	.80	.72	.61	.61	16	13	13	0.9	0.8	0.8
Diesel Powered Motor Vehicles	87	1 02	1 01	.67	.79	.78	8	9	9	0.5	0.5	0 5
Aircraft												
Jet	.91	88	.88	52	.50	.50	10	10	10	0.6	0.6	0.6
Piston	66	74	.72	81	91	.89	18	20	20	1.0	1.2	1.2
	.70	66	66	67	64	.63	1749	1660	1641	100%	100%	100%

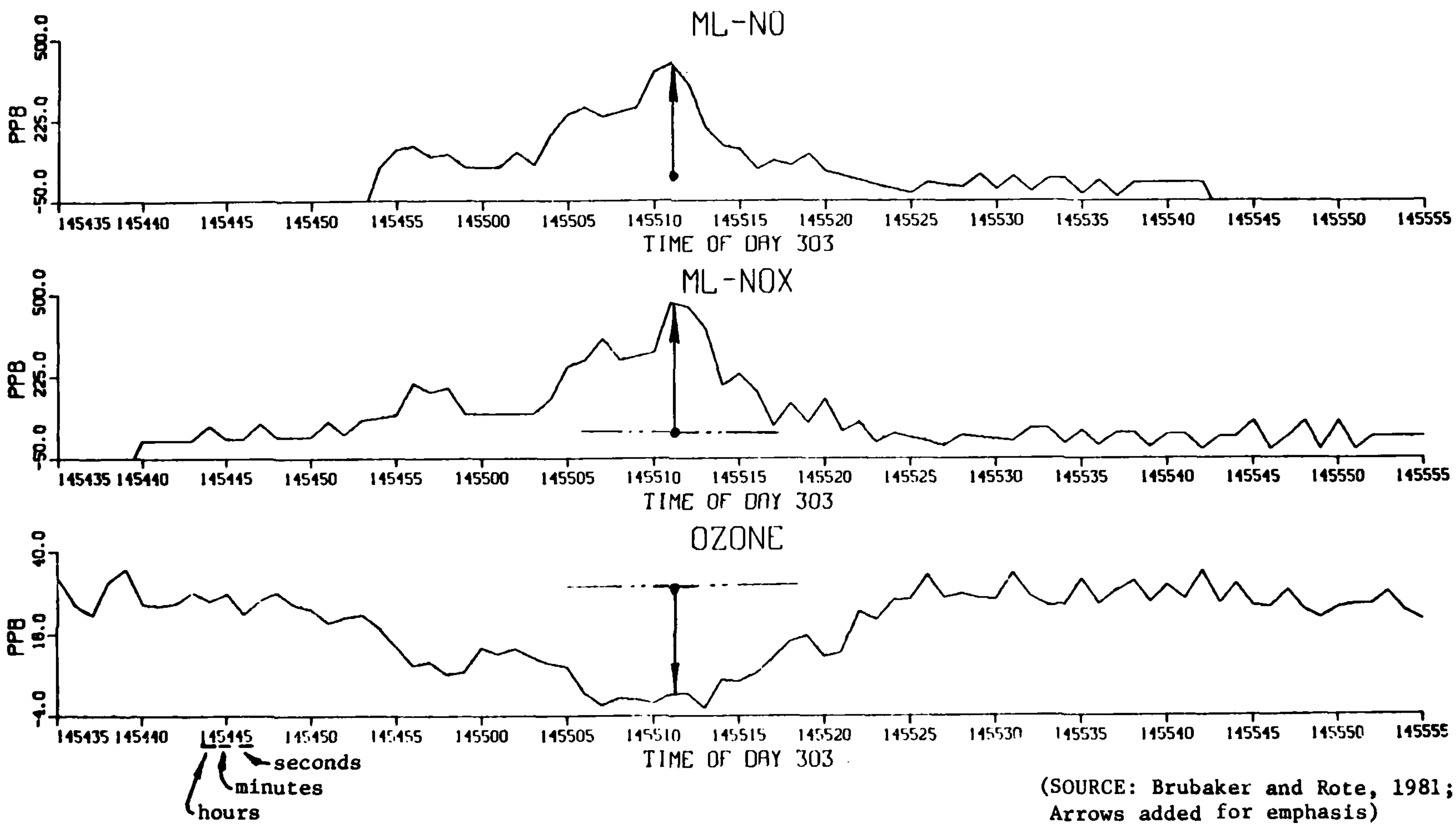
(SOURCE: Trijonis and Arledge, 1976)

0.2 to 0.5 ppm for which a short-term NO_2 NAAQS is being considered. This suggestion is based on dispersion model results and on an extrapolation of measured NO_2 ambient data.

In each case the total NO_x from aircraft is assumed to be NO_2. This may eventually happen but not necessarily before substantial atmospheric dilution has taken place. Roughly 94% of the NO_x is emitted by aircraft as NO yet health effects are only linked to NO_2. A portion of the NO to NO_2 conversion can be nearly instantaneous as shown in Figure VIII-6. However, the rate depends largely on the ambient O_x available. Thus very rapid conversion to a 0.4 ppm NO_2 level would require about a 0.4 ppm level of O_x which is unlikely. Preliminary measurements several hundred meters from an aircraft plume suggest that less than one-third of the NO_x is NO_2. Further work in measuring and monitoring this conversion rate near aircraft plumes is currently underway (Brubaker, 1981).

D. Cost Effectiveness Studies

Four studies have been published which evaluate the overall costs and cost effectiveness of aircraft engine emission controls. Only the latest of the three EPA studies, Wilcox and Munt (1977), Wilcox and Munt (1978), and Wilcox (1979), will be used since it superseded information in the previous reports. The Logistics Management Institute (LMI) report by Day and Bertrand (1978) is an independent and somewhat broader economic study aimed at overall costs. Cost effectiveness ratios from these studies will be related to other non-aircraft control alternatives. All costs are in terms of 1978 dollars where a discount rate of 10% is assumed.



(SOURCE: Brubaker and Rote, 1981;
Arrows added for emphasis)

AMBIENT OZONE DECREASE RESULTING FROM AIRCRAFT PLUME
FIGURE VIII-6

1. Aircraft Engine Control Costs

The LMI report computes the overall costs of the aircraft engine standards proposed in 1978. Costs of between $1.5 billion and $2.8 billion were estimated. The very large uncertainty range is primarily due to the NO_x controls which necessitate a major change to advanced technology combustors. The costs of this high risk development program and unknown maintenance problems from the greater mechanical complexity are poorly understood.

The economic impact on the United States airlines are estimated by Day and Bertrand (1978, p. 32) as follows:

Total Costs of Compliance: $0.9 to $1.6 billion in the U.S., and $1.5 to $2.8 billion worldwide. (Includes proposed 1981 NME, 1984 NME, and 1985 IUE standards.)

Engine Prices: 1981 NME Standard = 1.5%
1984 NME Standard = 11%-17%

Aircraft Prices: 1981 NME Standard = 0.3%-0.5%
1984 NME Standard = 1.6%-3.2%

Airline Fare Increases: 0.2%-0.77%

Airline Demand Decreases: 0.34%-0.54%

Outside Capital Requirement Increase: 14%

Gross Capital Requirement Increases: 2.7%

The proposed emission control standards are concluded by Day and Bertrand to have a minor impact on the airline industry in most cases. Conversely, the costs cannot be deemed insignificant. Engine price increases of 11% to 17% and additional outside capital requirements of 14% warrant serious concern by industry management. Since the sole source of cost estimates in this LMI study was the airline industry, EPA has judged that these estimates may be conservatively high.

The National Commission on Air Quality (NCAQ, 1981, p. 4.1-4) reported that increases due to air pollution controls by all United States industries averaged 2.38% of the total capital expenditures. Costs ranged from 0.19% for the railroad industry to 11.06% for the steel industry. The total capital costs of air pollution control to the airline industry of 2.7% are consequently slightly above the national average but well within the range of costs experienced by other industries.

The Wilcox (1979) report is an involved cost effectiveness study which by definition considers both costs of control and the reductions in emissions. Calculations based on data from this report are shown in Table VIII-4. They are in the order of several hundred dollars per ton of pollution eliminated for THC and CO. The conclusion of Hypothesis H-5 was that there is no significant CO air quality problem from aircraft engines. All THC and CO control costs are therefore burdened to THC. The resulting ratio of $400 per ton is for engine life-time costs and reductions. Assumed life-times are 15 years for new engines and as little as 7 years for some in-use engines which are retrofitted.

2. Cost Effectiveness Comparisons

Although cost effectiveness estimates are now prepared for new emission standards, EPA has no formal policy of what values are deemed cost effective or not cost effective. Informal judgements are apparently made during the standard setting process and are likely to change with time. As additional standards are issued for efficient control strategies, the remaining strategies will have higher cost effectiveness ratios until adequate emission reductions are attained.

TABLE VIII-4

AIRCRAFT ENGINE CONTROL COST EFFECTIVENESS COMPUTATION (1978 DOLLARS)(1)

Control Increment	Engine Control Cost ($)	Engine Costs -"Sunk Costs" ($)	Engine Life (Yrs)	Capital Recovery Factor	Annualized Annual Operating Increment(4): Capital Costs(3) ($/Yr)	Fuel @ Idle ($/Yr)	Fuel @ Cruise ($/Yr)	Maintenance ($/Yr)	Total Annual Control Costs ($/Yr)	Pollution Reduction (Tons/Yr/Avg. Engine): THC	CO	NO_x	Cost Effectiveness(5) ($/Ton): THC	CO	NO_x	Cost Effectiveness(6) ($/Ton): THC
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Modified Production Combustors. THC & CO control only on newly manufactured engines. (1981 NME Std.)	40,800	26,100	15	0.1315	3,432	1,142	0	632	5,206	16.4	20.8	0	160	125	N/A	320
2. Above technology retrofitted to in-use engines. (1985 IUE Std.)	41,200	31,800	13	0.1408	4,477	1,052	0	604	6,133	15.4	19.8	0	200	155	N/A	400 Best Estimate This Work
3. Above technology plus NO_x control with advanced technology combustors. (1984 NME plus 1981 NME & 1985 IUE Stds.)(2)	56,000	39,800	10	0.1628	6,479	628	0	526	7,633	12.2	16.9	0	310 (EPA Allocation Method)	230	9,700	
	57,200	53,300	15	0.1315	7,009	-2,170	+1,128	42,500	48,467	0	0	5.0			10,200(7)	400 Best Estimate This Work

(1) Columns (2) through (13) are unit costs per "average engine" as defined in Wilcox (1979). Wilcox Tables 2, 10, 17, 18 and 20 were used in these calculations.

(2) The first row represents the 1981 NME and 1985 IUE related costs. The second row represents the 1984 NME related costs.

(3) Annualized Capital Costs = Column (3) x (5) (10% discount rate is assumed).

(4) Annual Operating Increments = (7) + (8) + (9).

(5) Cost Effectiveness (equal THC and CO assumed) = (6)+(10) / (11) x 50% for THC and (6)+(10) / (12) x 50% for CO.

(6) Cost Effectiveness (no CO air quality benefit assumed) = (6)+(10) / (11) for THC.

(7) All costs above $400/Ton THC reduced are burdened to NO_x control: $\underbrace{\text{Total Costs (\$48,467 + \$7,633)}}_{\$56,100} - \underbrace{\text{THC Costs (\$400 x 12.2)}}_{\$4,880}$ = NO_x Costs = \$51,220/5.0 = \$10,200/Ton NO_x

Cost effectiveness ratios of sources for which Federal standards have been implemented or are under serious consideration are presented in Table VIII-5. Aircraft emission control costs from the previous table are compared with other source categories. These costs are \$125 to \$230 per ton of CO if the costs are evenly divided between CO and THC. They appear on the high side of the \$50 per ton for the few sources shown for CO but are not completely unreasonable from the little data available and the uncertainty of such calculations. Estimated aircraft THC cost effective values at \$400 per ton are well within the range of other strategies. This is even true if all THC and CO costs are burdened to THC. Federal standards cost up to \$1,000 per ton of THC and appear to be in line with those considered by states to meet oxidant NAAQS levels.

The aircraft NO_x costs of \$9,700 per ton to \$10,200 per ton are well above those of other strategies. If this value is accurate, aviation controls would appear unreasonable. Unfortunately, the accuracy of this estimate is hard to verify. The most important cost component is also the most uncertain. An annual maintenance expense of \$42,500 per engine was estimated to result from the greater complexity of the advanced technology required. This cost is due to the introduction of immature and unknown hardware and to a reduction in combustor durability. Since \$8,500 per ton NO_x of the total \$9,700 per ton is due to this maintenance cost estimate, its importance cannot be over-estimated.

E. Event Trees

A common hinderance to the use of dispersion models in decisions is that estimates of uncertainties about the predicted values

TABLE VIII-5

COST EFFECTIVENESS FOR NON-AIRCRAFT CONTROL STRATEGIES
(1978 DOLLARS)

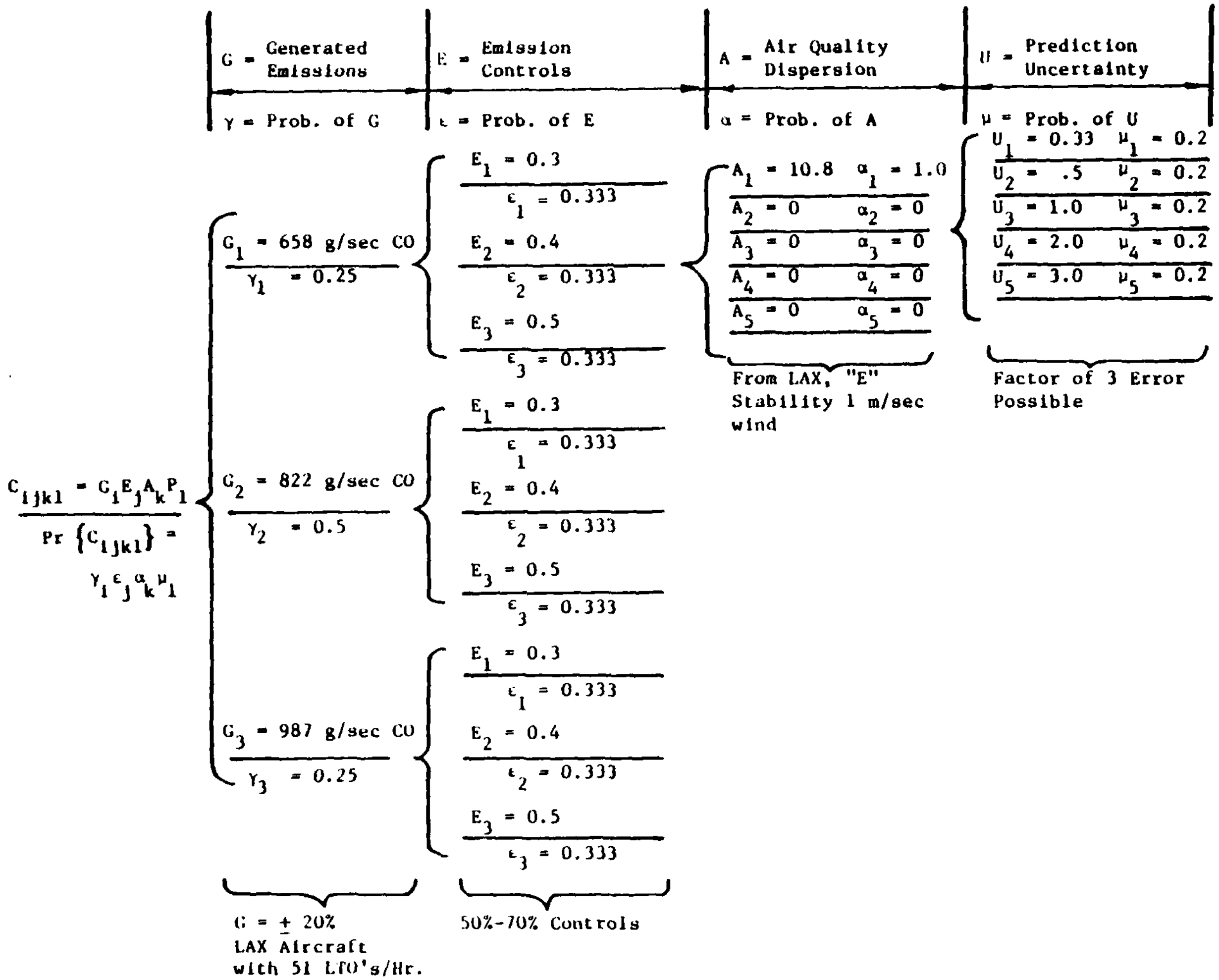
Control Strategy	Cost Effectiveness ($/ton) THC	CO	NO_x
I. Sources for which Federal standards are implemented or are under serious consideration. (SOURCE: Compilation from numerous sources as presented in Wilcox, 1979, p.60)			
Degreasing 0-48%	-230(Savings)		
Gravure 0-98%	- 60		
Gas Terminal 0-67%	0		
Miscellaneous Chemicals 0-35%	0		
Dry Cleaning 0-80%	10		
Gas Heavy Duty Vehicle Evap. 5.8-0.5 g/mi.	20		
Degreasing 41-90%	100		
Industrial Finishing 76-97%	110		
Gasoline Handling 16-50%	110		
Miscellaneous Chemicals 35-53%	220		
Gasoline Distributions 67-99%	300		
Coke Ovens 0-80%	490		
Light Duty Vehicle Exhaust 0.9-0.41 g/mi	530		
Gas Handling 51-91%	780		
Gas Heavy Duty Vehicle 90% of Baseline	300	8	
Diesel Heavy Duty Vehicle 90% of Baseline	162		
Light Duty Vehicle Inspection & Maintenance	955	49	2,763
Light Duty Truck 1.7-0.8 g/mi	139-201		
Motorcycles 9 to 8-22.5 g/mi	420		
Motorcycles 34.67-27.4 g/mi		neg.	
Light Duty Vehicle 15-3.4		48	
Light Duty Vehicle 3.1-0.4			2,700
Stationary Engines 0-75%			400
Utility Boilers 0-90%			1,400
II. Regional Sources as evaluated by the National Commission on Air Quality(1981, p.4.1-29). Full control costs are attributed only to reduction in hydrocarbons. Some proposed source controls are as follows:			
1. Los Angeles Region:			
Numerous Source Categories	400		
Machinery Surface Coating	1,239		
Vehicle Inspection & Maintenance	1,258		
Vegetable Oil Processing	2,908		
Auto. Factory Surface Coating	6,281		
Wood Furniture Coatings	8,260		
2. New York Metropolitan-Connecticut Region:			
Degreasing Activities, Cut-Back Asphalt, Gas Terminals	-450 (Savings)		
Numerous Controls (Can, Coil, Wire, Fabric, Paper & Appliance Coating Activities)	25-350		
Vehicle Inspection & Maintenance (Conn.)	1,035		
Automobile Coating	1,287		
Vehicle Inspection & Maintenance (NY City)	1,563		
Gasoline Stations	2,012		
Small Appliance Manufacturing	13,058		
3. Twin Cities Region:			
Numerous Controls on Petroleum Refineries, Surface Coatings, Gasoline Marketing	155-466		
Vehicle Inspection & Maintenance	2,235		
Fuel Storage Tanks	2,264-6,108		
Appliance Coating	Up to 3,483		
Automobile Coating	Up to 10,100		
III. Aircraft Engine Emission Controls as Proposed in 1978 (From Table VIII-4)			
Newly Manufactured Engines	320*		
(Modified Conventional Combustor Technology)	or 160	125	
Retrofit to In-Use Engines	400*		
(Same Technology as Above)	or 200	155	
Newly Manufactured Engines	400*		10,200*
(Advanced Combustor Technology as an Increment to Above)	or 310	230	9,700
IV. Other In-Use Aviation Control Strategies (From Table A-10-2)	-3,857(Savings)		

*Suggested in this work. All THC and CO costs attributed to THC reductions. Other values shown attribute half of THC and CO total costs to CO and half to THC (EPA Method).

are rarely given. A technique using event trees offers promise in overcoming this shortcoming. A broad range of uncertainties can be handled by constructing event or decision trees and associated probabilities. The term "trees" is used since from one origin or "trunk" can come many chance outcomes or "branches". Each "branch" can in turn have many offshoots until a "tree" of possible outcomes are depicted. This approach has a wide variety of potential applications within the broader field of risk assessment.

Moreau (1979) illustrated a conceptual way that event trees can be useful to relate air pollutant source emission levels to the range of resulting air quality concentrations. An application of this concept to Los Angeles International Airport (LAX) emissions is shown in Figure VIII-7. Computations of input data are included in Appendix C. A range of air quality concentrations (C) are predicted from the generated emissions (G_i), emissions control factors (E_j), air quality dispersion factors (A_k) and uncertainty of prediction factors (U_l). Each of the above factors (G,E,A,U) are associated with a probability of occurrence (γ_i, ε_j, α_k, μ_l). An individual concentration (C_{ijkl}) is a linear multiple of each element with a probability of occurrence (P_{ijkl}).

Independence between G,E,A, and U is assumed since quantitative correlations do not exist for airports. This assumption is reasonable for prediction of a specific "worst case" hour but is unreasonable for attempts to predict the spectrum of all hours in the year. In the latter case, the G and A are dependent variables since both are functions of the diurnal time period. An airport measurement/dispersion model study has also shown that U is related to A (Yamartino, et.al., 1980, p. 42).



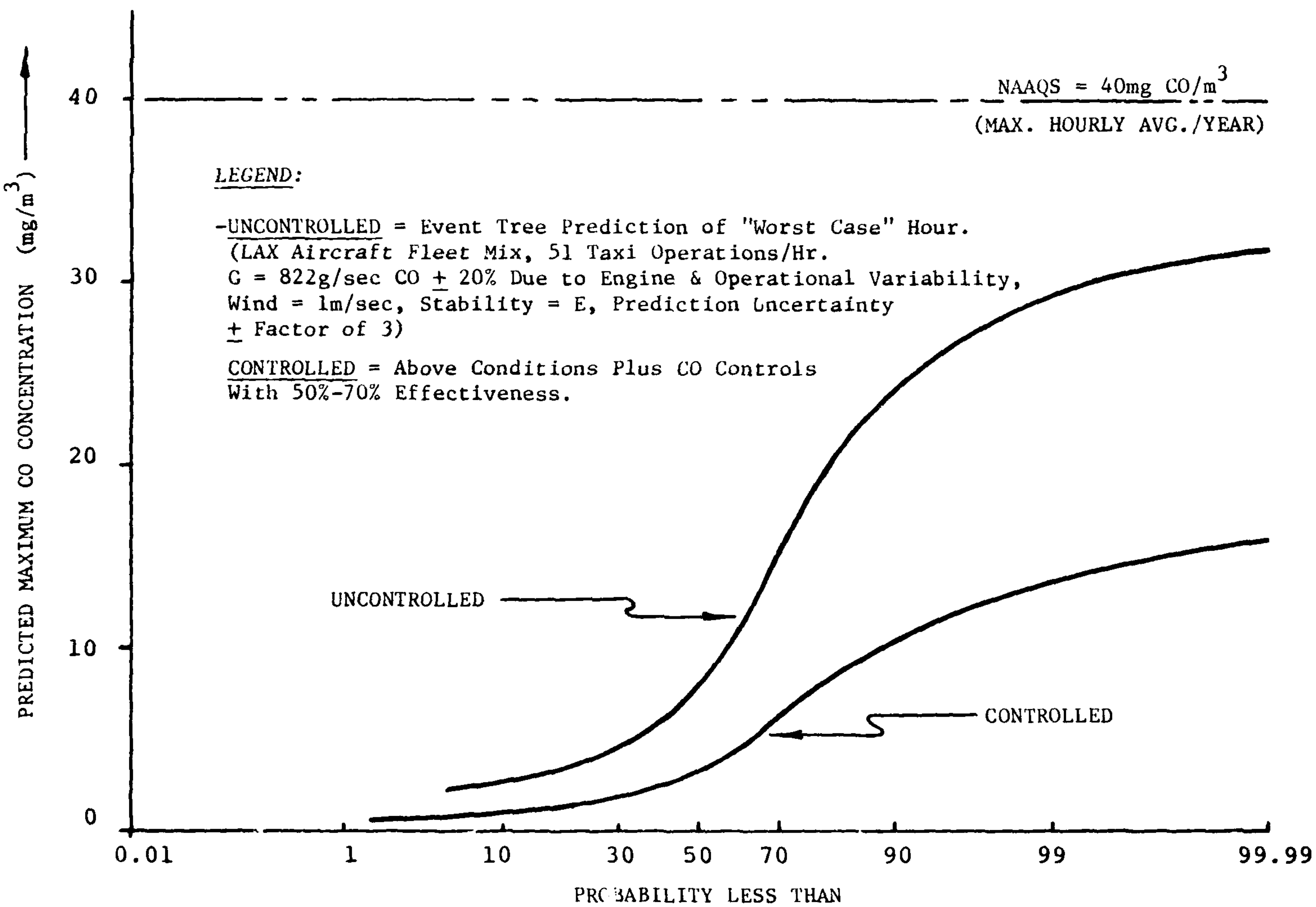
EVENT TREE SCHEMATIC AND INPUT DATA
FIGURE VIII-7

The best estimate of emissions (G) is made from a determination of a typical aircraft fleet mix at LAX and from published emission factor data. Assumed aircraft activity of 51 LTO cycles during the "worst case" hour produce emissions of 822 g/sec of CO. An emission variability of $\pm$ 20% within this hour is assumed to account uncertainties in engine emissions and aircraft activity within this hour. Possible emission control factors (E) equivalent to a 50%-70% reduction of CO are based on the conclusions of Hypothesis H-4.

The air quality dispersion factor (A) was computed with the simple model procedures outlined in the EPA workbook of dispersion estimates (Turner, 1970). A stable early morning "E" stability with a low 1 meter per second wind speed are assumed to represent the "worst case" hour to be compatible with CO short-term NAAQS comparisons. The dispersion factor is the normalized ambient air quality to emission (χ/Q) ratio.

The uncertainty of prediction (U) values are selected to account for under-predictions and over-predictions of up to a factor of 3.0. This appears to be a reasonable estimate for airports based on a detailed study of airport dispersion model performance (Yamartino, et.al., 1980b, p. 109). The assumed probability values γ, α, and μ represent "reasonable estimates" and are obtained much in the way values in a sensitivity analysis are selected.

A computer code (Appendix C) was written to rank-order all predicted concentrations and pair with the cumulative probabilities of occurrence. Results suggest that violations of the NAAQS for CO are not predicted at the 99.99% confidence level (Figure VIII-8). While predictions are dependent on a number of assumptions, each is



EVENT TREE PREDICTION OF CO CONCENTRATIONS FROM AIRCRAFT

AD-A107 435 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 1/2
CONTROL OF AIR POLLUTION FROM AVIATION: THE EMISSION STANDARD S--ETC(U)
1981 D F NAUGLE
UNCLASSIFIED AFIT-CI-81-26D NL

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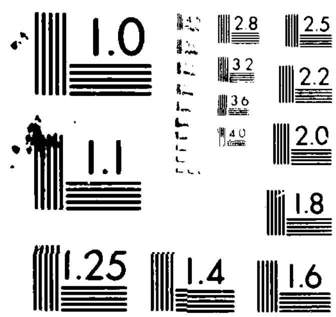


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

plainly stated and easily altered. Applications of the event tree approach suggest that with reasonable assumptions concerning the CO emissions at one of the largest United States airports (LAX), the probability of exceeding the CO hourly NAAQS is remote.

F. Summary

A summary of the alternate standard setting techniques discussed in this chapter is considered in Table VIII-6. Different techniques are often shown to suggest different conclusions. Since no technique is clearly superior to the others, the following judgements and conclusions are made from consideration of all of the techniques:

1. Carbon Monoxide

The weight of the evidence suggests that standards for the control of CO from aviation sources is not currently warranted. While the technology for 50%-70% control is available, the ambient measurements, dispersion models, and event tree results have not identified any air quality problem to be solved. The cost effectiveness of the proposed EPA control levels is also higher than other sources for which standards are contemplated. A comparison of CO emission densities is the only technique which suggests that controls might be needed. Airport to county densities significantly increase between 1975 and 1995. These projections are made on totally uncontrolled aircraft engines. Any THC controls would also lower CO emissions and would alter these projections.

2. Total Hydrocarbons

Essentially all of the techniques considered lead to the conclusion that THC aviation emission controls are suggested. Technological improvements can effect a 70%-90% emission reduction and are cost effective when compared to other source strategies. Many parts

TABLE VIII-6

SUMMARY OF STANDARD SETTING TECHNIQUES

Technique	AVIATION CONTROLS SUGGESTED? THC YES	THC NO	NO_x YES	NO_x NO	CO YES	CO NO
1. Best Available Control Technology	X (1) (70-90% Reduction)		X (1) (30-50% Reduction)		X (1) (50-70% Reduction)	
2. A. Emission Comparisons	X (11th Highest with Stationary Sources)	X (1.2% of U.S. Emissions)	X (Increasing Importance)	X (New 0.6% of U.S. Emissions)		
B. Emission Densities		? (Some increasing, some decreasing importance of airports compared to other sources)	X (Increasing Importance of airports compared to other sources)		X (Increasing importance of airports compared to other sources)	
C. Rollback Models						X (Ambient measurements on airports suggest rollback to NAAQS levels not needed)
3. A. Dispersion Models				X (Annual NO_x concentrations from aircraft-no problem)		X (No existing problem from aircraft)
B. Photochemical Studies	X (Serious nationwide O_3 problem requires stringent THC controls on virtually all sources)		? (Short-term NO_2 violation potential?)			
4. Cost Effectiveness	X ($400 per ton THC reduced is well below the costs for other sources)			X ($10,000 per ton NO_x reduced is well above costs for other sources)		X (Estimated costs of $125-$230 per ton CO reduced is above the $50/ton costs for other sources)
5. Event Trees						X (Best estimates combined with emission, control and dispersion uncertainties suggest a small probability of CO NAAQS violations)

(1) Estimated from data in Appendix A-4.

of the United States have ambient O_x levels above those deemed to cause potential health effects. Reductions by many sources of the THC precursors to O_x formation, including those the size of airports, appear to be needed to reduce these O_x levels. The relative importance of airport emissions compared to county emissions is highly variable from area to area. Some airport/county ratios are predicted to increase between 1975 and 1995 while others will decrease, even without emission control standards.

3. Oxides of Nitrogen

The evidence concerning the need and effectiveness of standards for control of NO_x emissions from aircraft is mixed. The technology for control is not as effective as for THC or even CO. Reductions in the order of 30%-50% may be possible but only with implementation of largely unproven advanced technology combustor designs. At $10,200 per ton of NO_x eliminated, the cost effectiveness of these controls is well above those for other sources. Also, a link between airport NO_x emissions and any real air pollution problems has not been demonstrated.

The prime argument for establishing NO_x aircraft emission standards is to mitigate the potential for future problems. Airport NO_x emission densities are not typically greater than those in surrounding counties. For all 20 of the large commercial airports analyzed, the ratio of airport to county emissions will increase between 1975 and 1995. The rate of projected increase in aircraft emissions is confirmed and more graphically illustrated in the next chapter. The level of stringency for NO_x aircraft emission standards and whether such standards should be set at all is currently difficult to determine from all available technical evidence.

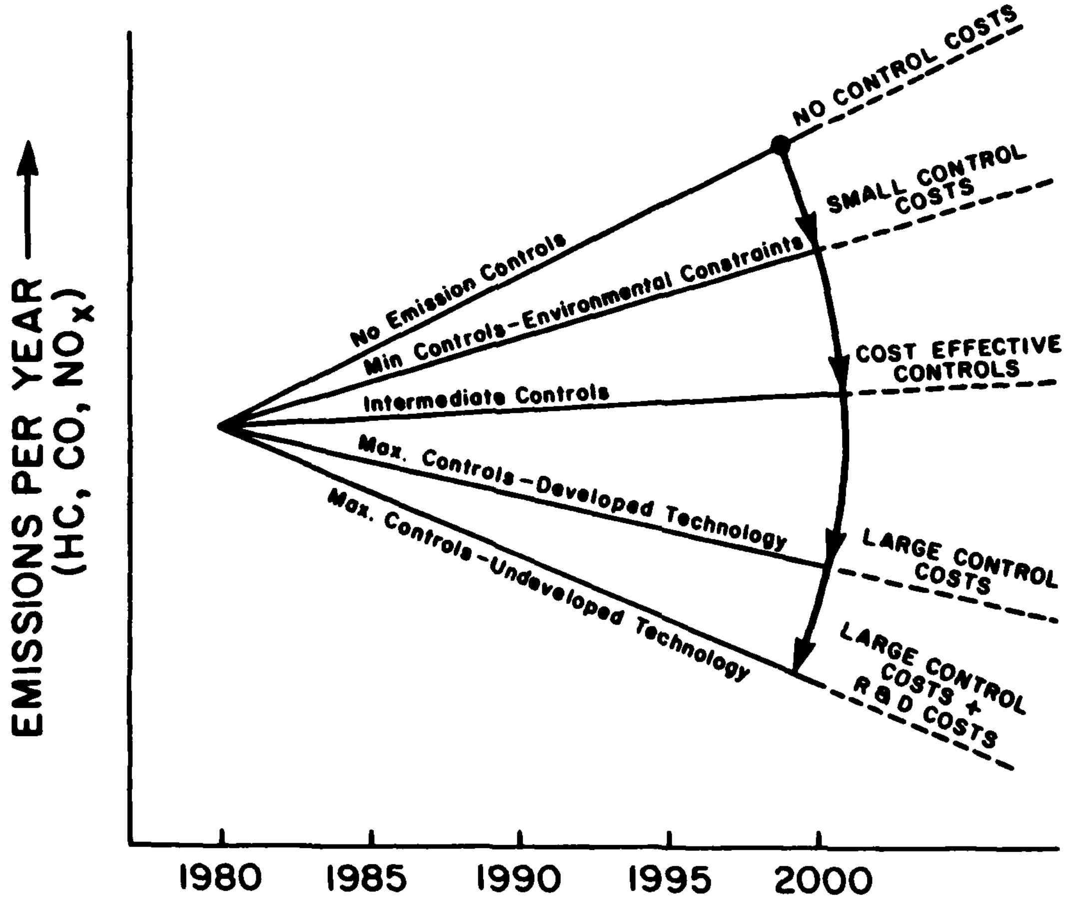
CHAPTER IX

AVIATION CONTROL OPTIONS

The information to establish emission standards would ideally include accurate projections of source emissions from control strategies and the associated incremental costs of compliance. This information is conceptualized in Figure IX-1. The annual source emissions are projected for various control alternatives. The options have upper bounds of no regulated controls with no cost penalties. The lower emission bounds are established by the technological limits of control. This assumes the emission source is irreplaceable and cannot be eliminated by switching to other processes or systems with no source emissions. Control costs for the lower emission bounds include the research, development, test and evaluation of new concepts in addition to the capital and operational costs of implementing the controls.

A range of public policy choice in this figure illustrates that there are legal environmental constraints to protect human health and welfare which may necessitate some level of control. Technological constraints can be established as a matter of policy at levels of maximum demonstrated or even undemonstrated technology. There is normally a range of options in between the environmental constraints of adverse health and welfare effects and the maximum technological constraints.

In practice, the emission reductions and costs from control standards are never known with perfect certainty and are often rough estimates. The marginal costs are typically known at only a



ENVIRONMENTAL AND TECHNOLOGICAL CONSTRAINTS, COSTS, AND EMISSIONS

FIGURE IX-1

very few control increments. Levels of control to meet environmental and technological constraints result from judgements which are apt to be controversial. The levels are rarely well defined functions which can be technically validated. The evaluation of emission control options must somehow take place within this setting of complexity and uncertainty.

The most elaborate and presumedly most accurate aviation source projections are contained in the FAA Airport Emissions Data Base. The computer program and input data were developed by ORI, Inc. under FAA contract (Bauchspies, et.al., 1978). It is specifically designed for the evaluation of alternative airport emission control measures and their effect on the local air quality region. Pollutant emissions are computed for THC, CO, and NO_x.

The data base now includes actual air traffic operations for 1978 and forecasts for 1980, 1985, 1990, and 1995. The accuracy of the forecasts can be expected to decrease with the longer range of projections due to greater uncertainties. Aircraft emissions are generally consistent with EPA data (U.S. EPA, 1980a). Additional, more recent data from engine test programs by engine manufacturers is included when available. They were updated recently and are considered as 1980 data.

The future projections of engine emissions data involves assumptions made by ORI, FAA, and in some cases the engine manufacturers. Projections which involve the emissions of engines not as yet certified, the mixture of aircraft/engines, or times spent in each of the landing and takeoff (LTO) operational modes at various airports are subject to undetermined errors and uncertainties. All assumptions and projections within the FAA Airport Emissions Data Base are assumed to be correct in this work.

Special computer runs were supplied by ORI under FAA direction (Bauchspies and Krull, 1981). Emissions for four control scenerios were run:

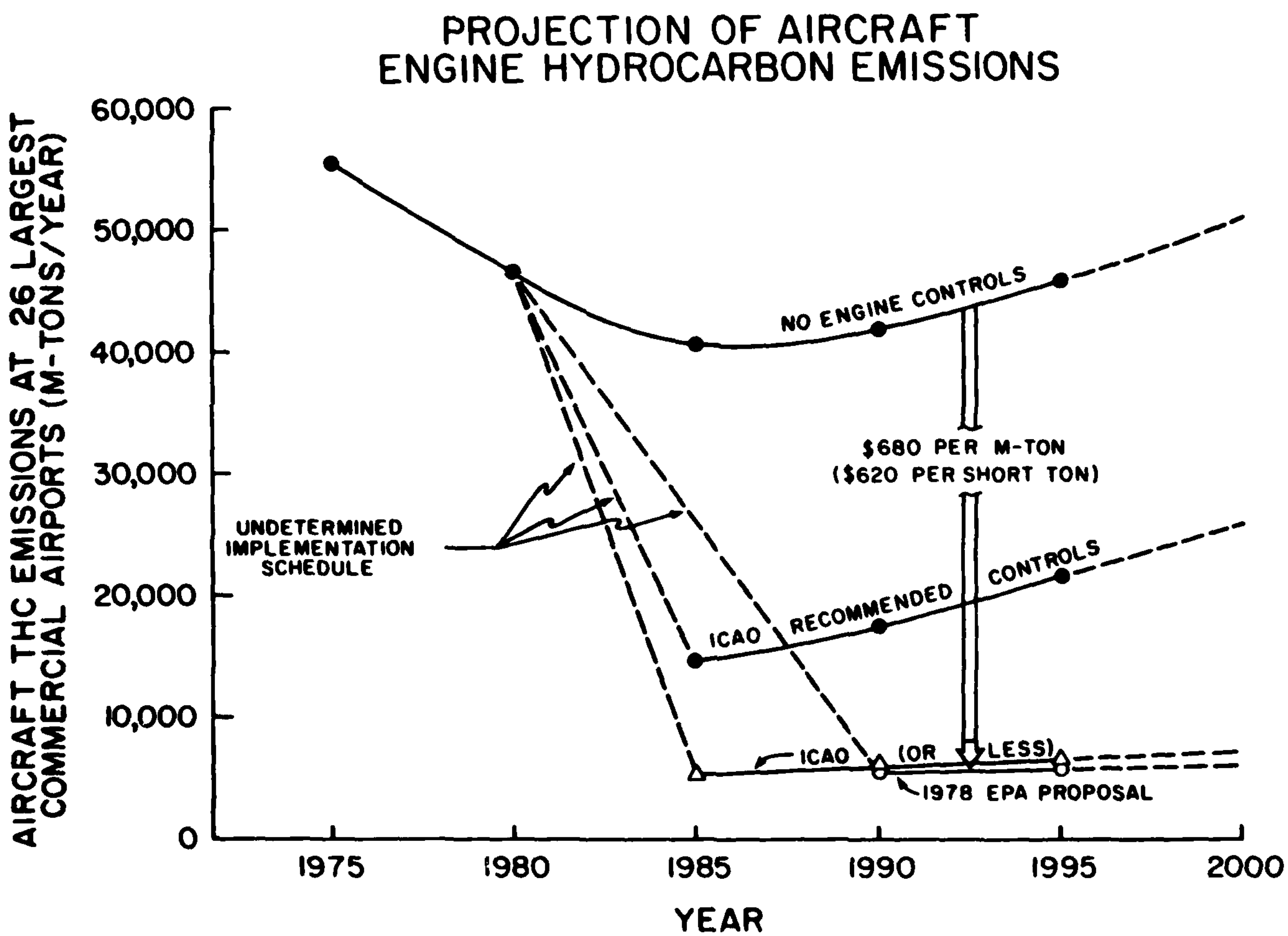
(1) "Baseline" Case - No aircraft engine emission controls are assumed;

(2) "Retrofit + 5 Years" Case - Levels proposed by EPA in 1978 are assumed to be met. A 5 year delay is assumed so that 1981 NME standards were assumed to be fully implemented by 1986, 1984 NME standards by 1989, and the 1985 IUE (Retrofit) standards by 1990;

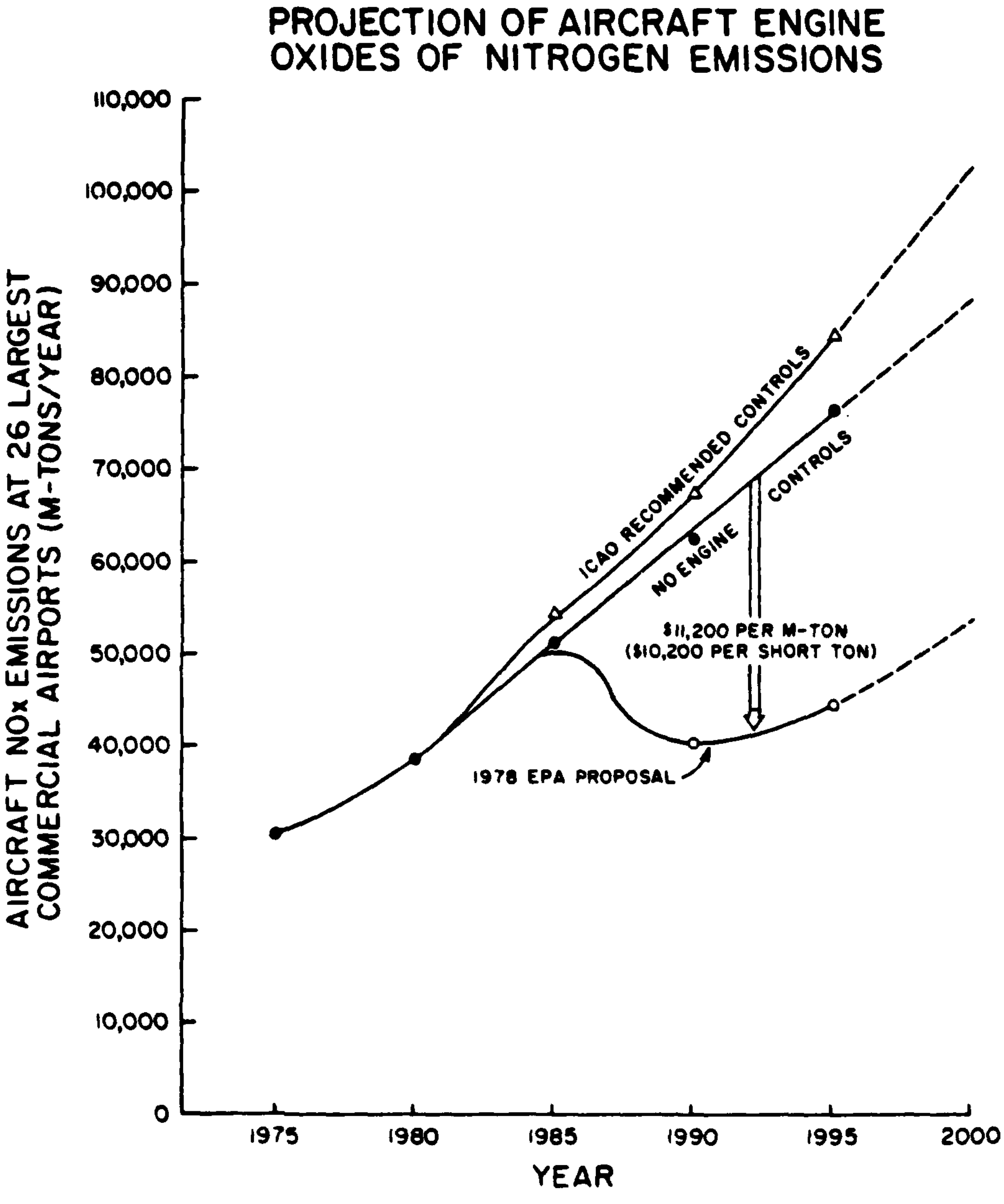
(3) "ICAO" Case - The 1980 recommended ICAO standards are assumed to be exactly met (no margin of safety). NO_x emissions below ICAO levels are not increased to the ICAO levels;

(4) "ICAO-I" Case - Engines are at or below the ICAO standards. This scenerio was added since manufacturers have stated that if they have to implement emission reduction hardware, the best technology will be used and may be far less than the ICAO levels for many aircraft engines.

Results for each of the four scenerios are shown in Figure IX-2 for THC and Figure IX-3 for NO_x. The CO projections are not analyzed in this chapter since their air quality benefits were concluded to be insignificant. They are included in Appendix B for completeness. Data base projections in 5 year increments from 1975 through 1995 are shown along with graphical extrapolations to the year 2000. In each case the projections are the sum of all aircraft engine emissions at the 26 large commercial airports now programmed in the data base. Results for individual airports are included in Appendix B and are useful to show the airport to airport variations. Data for 13 general aviation airports is also available but are not used in this



PROJECTION OF AIRCRAFT ENGINE HYDROCARBON EMISSIONS
FIGURE IX-2



PROJECTION OF AIRCRAFT ENGINE OXIDES OF NITROGEN EMISSIONS

FIGURE IX-3

work since standards have been dropped by EPA.

Without emission controls, the THC aircraft emissions will slightly decline until about 1985 and then increase due to greater airport activity (Figure IX-2). The initial decline is from the attrition of older aircraft engines which will be replaced by ones with higher combustion efficiencies. The effectiveness of the EPA proposed control levels for THC is obvious. Reductions from the baseline are in the order of 85%. The costs per ton shown are from Table VIII-4.

Projections of the ICAO-I case are surprisingly close to the EPA levels. This tends to confirm the conclusion in model Hypothesis H-7 that the EPA proposed controls are technologically reasonable. It is debatable, however, if emissions reductions would actually reach the ICAO-I levels when the ICAO standards are so much higher. Cost estimates of the ICAO standards are not known to exist and consequently cannot be shown.

Sizeable increases in airport NO_x emissions are projected through the year 2000 if engine controls are not implemented (Figure IX-3). Increases result both from expected air traffic growth and from emissions per aircraft LTO cycle. The per cycle emissions come from the trend toward more fuel efficient higher temperature engines which are typically higher in NO_x (but lower in THC) emissions.

The EPA proposed NO_x standards are effective in slowing the trend of NO_x increases but do not cause significant overall reductions. Annual emission levels in the year 2000 are projected to be about the same as in 1985 even with an average control effectiveness of 65%. Also, as concluded in H-7, the EPA levels are too stringent for many engines due to the advanced technology involved. Emission reductions are likely to be less than shown. The costs of $10,200 per ton amortized over a 15 year engine life are well above those of other NO_x sources.

The alternative of no controls would lead to a 100% projected increase between 1980 and the year 1995. Adoption of ICAO standards could lead to even larger increases. The technology to reduce THC and CO emissions below the ICAO limits is presumed to accelerate the switch to newer engines with higher combustor inlet temperatures which in turn increases NO_x emissions. The ICAO NO_x standards do not act as a ceiling to prevent NO_x from increasing.

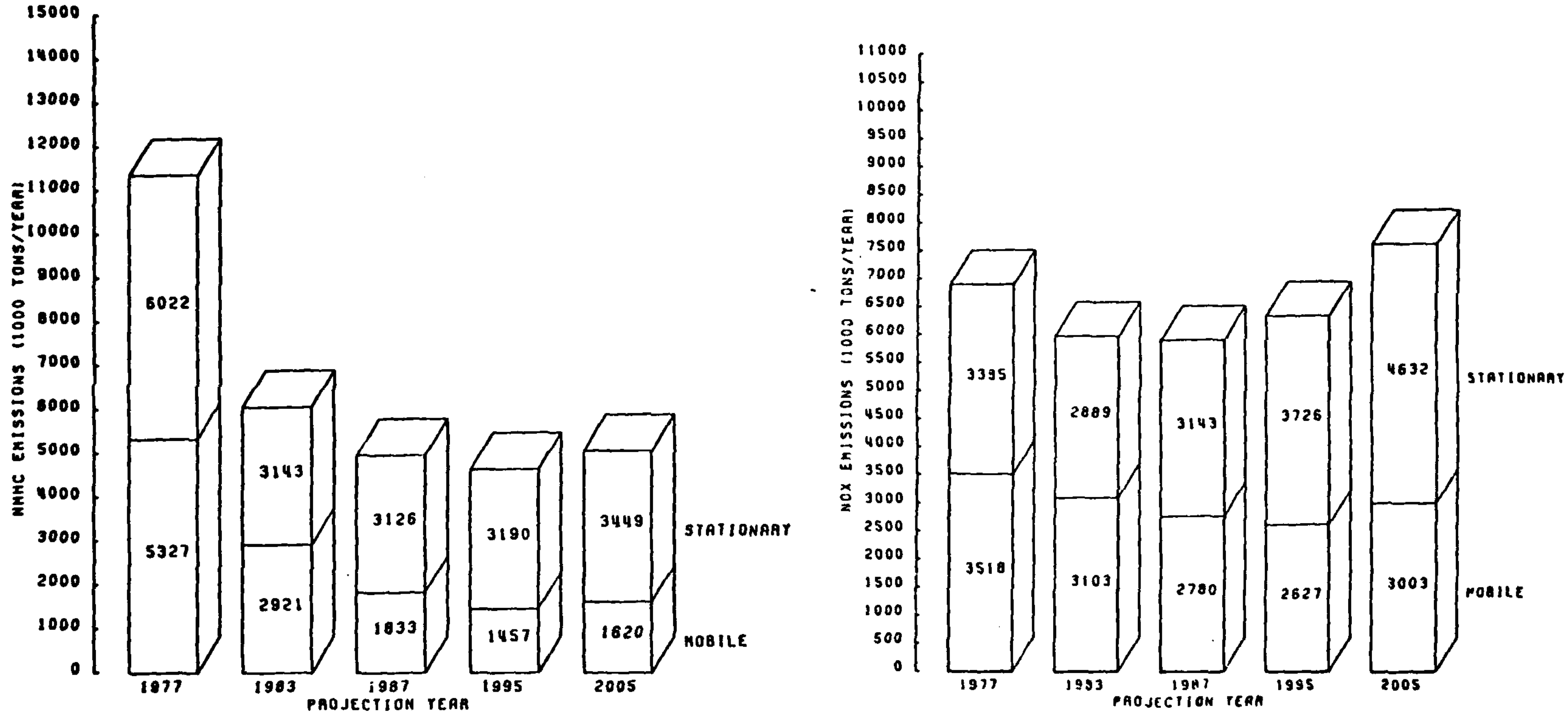
A comparative analysis was performed on these aircraft projections relative to other mobile sources and overall emission projections. The most accurate emission projections of mobile sources which could be found were prepared by the EPA Office of Mobile Source Air Pollution Control (Wolcott, 1980). This report is based on 1977 NEDS data and adds detailed computations to arrive at future projections through the year 2005. Computations are done using the EPA developed MOBILE 1 computer program. The most detail is given to highway motor vehicle emission projections. Aircraft and other non-highway mobile sources are assumed to have a 1% compound annual growth rate of emissions. The EPA data focuses on carefully selected counties in the nation. These counties were chosen from the nation's total 3,200 since they are identified with air quality problems. A joint list was prepared from the 146 counties with CO violations, 90 counties with projected NO_2 violations and approximately 500 counties with O_x violations.

The overall hydrocarbon projections from these counties show a sharp emission decrease from 1977 through 1995 and a slight increase by the year 2005 (Figure IX-4). This trend occurs for both stationary and mobile sources. Emission control programs are initially effective until growth factors again cause emission increases. The NO_x projections show slight initial decreases through 1987 but increases to 2005 and presumedly beyond.

Direct comparison of the detailed aircraft emission projections from the FAA Airport Emissions Data Base with this EPA data is not possible. The FAA data includes only 26 major commercial airports while the EPA data includes selected counties. In order to compare projections, the EPA base emissions were scaled up using the graphical projections in this chapter based on the FAA data. The results in Tables IX-1 and IX-2 are much different than the EPA projections based on a 1% growth rate.

Without controls, aircraft can account for 7.8% of all mobile hydrocarbon emission sources by the year 2005. This is an increase from 1.0% in 1977 to 2.5% of all sources by 2005. Aircraft emissions controls effectively reduce any impact to 0.3% of all sources.

Uncontrolled aircraft NO_x emissions rise even faster from 2.3% to 11.2% of the mobile sources between 1977 and 2005. This is equivalent to 1.2% through 3.3% of all sources in the same time periods. The EPA proposed NO_x standards would reduce the 2005 impact to 5.1% and 2.0% of the mobile and total sources. Actual reductions



(SOURCE: Wolcott, 1980)

EMISSION PROJECTIONS OF EPA SELECTED COUNTIES
FIGURE IX-4

TABLE IX-1

COMPARISON OF AIRCRAFT, MOBILE SOURCES, AND TOTAL EMISSIONS PROJECTIONS - HYDROCARBONS

NMHC : INVENTORY LEVELS SCENARIO : BASELINE

EMISSIONS (1000 TONS/YEAR)

MOBILE SOURCE CATEGORIES

	LDV-G	LDT1-G	LDT2-G	HDG	CYCLES	LDV-D	LDT1-D	LDT2-D	HDD	RAILROAD	VESSELS
BASE YR											
1977	3379.8	386.3	311.4	737.3	81.2	0.0	0.0	0.0	106.8	79.2	59.4
PROJ YR											
1983	1578.8	202.1	205.8	418.5	33.6	0.0	0.0	0.0	137.7	81.7	61.7
1987	820.7	128.4	133.9	252.8	7.7	0.0	0.0	0.0	127.5	85.8	64.3
1995	565.8	101.7	79.8	158.4	1.5	0.0	0.0	0.0	165.4	94.2	70.1
2005	625.2	112.7	65.4	126.2	2.0	0.0	0.0	0.0	258.1	104.3	78.5

	1% GROWTH AIRCRAFT	UNCONTROLLED AIRCRAFT	1978 EPA "CONTROLS" AIRCRAFT	FARM-G	LAWN	SNOW	INDMCH-G	CONST-G	FARM-D	INDMCH-D	CONST-D	MOBILE TOTAL	AIRCRAFT % MOBILE 1%	AIRCRAFT % MOBILE NO CONTROLS	AIRCRAFT % MOBILE EPA CONTROLS
BASE YR															
1977	115.8	115.8	115.8	9.5	0.0	6.8	21.2	6.7	2.4	3.0	13.3	5327.1	2.2	2.2	2.2
PROJ YR															
1983	121.4	93.5	93.5	9.5	0.0	6.8	21.6	6.7	2.4	3.0	13.3	2921.2	4.2	3.2	3.2
1987	127.2	91.2	91.2	9.6	0.0	7.1	22.1	6.8	2.5	3.0	13.3	1833.5	6.9	5.1	5.1
1995	138.2	101.3	12.7	10.0	0.0	7.8	23.5	7.1	2.5	3.1	14.3	1457.9	9.5	5.6	1.0
2005	152.9	124.7	15.1	11.0	0.0	8.7	27.0	7.7	2.7	3.2	16.1	1620.8	9.4	7.8	1.0

STATIONARY SOURCE CATEGORIES

			COMBUST		PETROL	STORAGE	INDUST	SOLVENT	STAT TOTAL	GRAND TOTAL	AIRCRAFT % OF TOTAL 1% GROWTH	AIRCRAFT % OF TOTAL NO CONTROLS	AIRCRAFT % OF TOTAL EPA CONTROLS
BASE YR													
1977	0.0	0.0	302.5	0.0	226.6	1031.3	429.3	4033.3	6022.9	11350.0	1.0	1.0	1.0
PROJ YR													
1983	0.0	0.0	302.5	0.0	29.2	232.0	328.0	2252.1	3143.4	6064.6	2.0	1.5	1.5
1987	0.0	0.0	302.5	0.0	33.4	251.5	367.1	2173.4	3127.0	4960.5	2.6	1.9	1.9
1995	0.0	0.0	302.5	0.0	43.2	294.6	465.7	2084.0	3190.7	4648.6	3.0	2.0	0.3
2005	0.0	0.0	302.5	0.0	55.1	359.1	638.3	2092.5	3449.4	5070.1	3.0	2.5	0.3

(SOURCE: All typed data from Wolcott, 1980. Data in blocks are projections from the 1977 EPA emissions using aircraft emission growth rates in the FAA Airport Emissions Data.)

Abbreviations

LDV-G = Light Duty Vehicle-Gas Engine
LDV-D = Light Duty Vehicle-Diesel Engine
LDT-G = Light Duty Truck-Gas Engine
LDT-D = Light Duty Truck-Diesel Engine
HDG = Heavy Duty Truck-Gas Engine
HDD = Heavy Duty Truck-Diesel Engine
INDMCH = Industrial Machinery
CONST-D = Construction Equipment-Diesel Engine

TABLE IX-2

COMPARISON OF AIRCRAFT, MOBILE SOURCES, AND TOTAL EMISSIONS PROJECTIONS - OXIDES OF NITROGEN

NOX : INVENTORY LEVELS SCENARIO : BASELINE

EMISSIONS (1000 TONS/YEAR)

MOBILE SOURCE CATEGORIES

	LDV-G	LDT1-G	LDT2-G	HDG	CYCLES	LDV-D	LDT1-D	LDT2-D	HDD	RAILROAD	VESSELS
BASE YR											
1977	1536.6	202.3	158.7	300.6	0.1	0.0	0.0	0.0	523.2	325.1	62.9
PROJ YR											
1983	1076.4	147.7	112.4	240.7	0.4	0.0	0.0	0.0	679.1	343.8	66.2
1987	951.1	125.0	86.0	185.7	0.2	0.0	0.0	0.0	552.9	359.1	68.8
1995	974.4	116.0	69.8	135.0	0.1	0.0	0.0	0.0	376.5	389.3	75.3
2005	1076.0	129.3	74.2	115.3	0.2	0.0	0.0	0.0	552.8	429.6	82.7

	1% GROWTH AIRCRAFT	UNCONTROLLED AIRCRAFT	"1978 EPA CONTROLS" AIRCRAFT	FARM-G	LAWN	SNOW	INDMCH-G	CONST-G	FARM-D	INDMCH-D	CONST-D	MOBILE TOTAL	AIRCRAFT % MOBILE 1%	AIRCRAFT % MOBILE NO CONTROLS	AIRCRAFT % MOBILE EPA CONTROLS
BASE YR															
1977	79.6	79.6	79.6	7.9	0.0	0.0	16.7	6.4	26.2	71.4	200.8	3518.4	2.3%	2.3%	2.3%
PROJ YR															
1983	83.2	111.0	111.0	7.9	0.0	0.0	16.9	6.4	26.6	73.0	211.6	3103.1	2.7	3.6	3.6
1987	87.1	135.1	135.1	7.9	0.0	0.0	17.3	6.5	27.5	77.9	221.8	2780.3	3.1	4.8	4.8
1995	94.3	184.0	108.3	8.4	0.0	0.0	18.4	6.8	29.2	85.0	240.0	2627.4	3.6	6.8	4.1
2005	104.6	253.3	154.4	9.0	0.0	0.0	20.8	7.4	33.2	94.2	265.1	3003.9	3.5	11.2	5.1

STATIONARY SOURCE CATEGORIES

	POINT		RES-OIL	COM-COAL	COM-OIL	IND-COAL	IND-OIL	OTHER	STAT TOTAL	GRAND TOTAL	AIRCRAFT % OF TOTAL 1%	AIRCRAFT % OF TOTAL NO CONTROLS	AIRCRAFT % OF TOTAL EPA CONTROLS
BASE YR													
1977	2838.0	0.0	180.8	3.7	174.3	29.1	113.0	46.6	3385.5	6903.9	1.2%	1.2%	1.2%
PROJ YR													
1983	2445.9	0.0	184.3	3.4	110.8	25.3	71.8	47.4	2889.8	5992.9	1.4	1.8	1.8
1987	2685.4	0.0	188.7	3.5	114.5	26.4	74.6	49.8	3143.6	5923.9	1.6	2.3	2.3
1995	3240.6	0.0	196.5	3.6	121.3	27.9	78.0	54.5	3726.5	6353.9	1.5	2.9	1.7
2005	4107.9	0.0	208.7	3.7	133.7	29.8	87.6	61.1	4632.1	7636.1	1.4	3.3	2.0

(SOURCE: All typed data from Wolcott, 1980. Data in blocks are projections from the 1977 EPA emissions using aircraft emission growth rates in the FAA Airport Emissions Data.)

are likely to be less than the EPA proposed levels due to technological difficulties.

While aircraft emissions are now a relatively small contributor to air pollution problems, their impact is likely to increase in the future. Implementation of hydrocarbon control standards, as proposed by EPA and to a lessor degree as proposed by ICAO, can completely reverse this trend. Unfortunately, the trend of increasing NO_x emissions from aircraft cannot be reversed even with the best known technology and very costly controls. Standards can serve to delay emission increases by roughly 15 years.

CHAPTER X

CONCLUSIONS

Application of the hypothesis decision model (as summarized in Table VI-1), comparison of various alternative standard setting techniques (as summarized in Table VIII-5), and consideration of the aviation control options (Chapter IX) have lead to the overall conclusions and recommendations. Both the conclusions and the recommendations in the next chapter are categorized into four subject areas: air quality assessments, cost of controls, control technology, and implications to standard setting.

A. Air Quality Assessments

Methods of air quality assessment used to evaluate aviation sources include emission analyses, dispersion modelling, and ambient measurement studies. Unfortunately, each method has flaws that make general scientific conclusions difficult. Emission analyses are readily understandable but are not directly comparable to air quality standards. Dispersion models explicitly relate aircraft emissions to air quality but can become so complex that they are hard to verify. They also suffer from unknown plume-rise and dispersion simulation errors. Ambient measurement data are difficult to interpret since concentrations caused by airports are not readily separated from those caused by other metropolitan sources.

Subject to the above shortcomings of the air quality assessment methods, the following conclusions are made:

1. Analyses of all current evidence suggest that aviation sources are not a direct cause of health and welfare effects. EPA thus would not have to issue aircraft emissions standards based on

the maximum control possible. Less stringent but more cost effective standards could be considered.

2. Emission and air quality data suggest that aircraft are a small part of overall air pollution problems. Potential health and welfare effects attributed to aircraft in pre-1973 studies have not been substantiated by more recent data. However, neither have these data established that hydrocarbon and oxide of nitrogen emissions from aircraft are insignificant contributors to pollution on a local scale. A rank-order of priorities for control is suggested:

Greatest Concern

- -THC: Based on nation-wide O_3 problems.
- -NO_x: Based on projected emission increases and possible short-term NO_2 ambient effects.
- -Smoke: Virtually eliminated in recently designed aircraft engines but may become a future problem if broader specification fuels such as those derived from shale oil are used.
- -CO: Not viewed as a serious problem from aircraft.
- -SO_x: No problems likely due to the low sulfur content in jet fuels needed for engine durability reasons.
- -Other Pollutants: No problems identified.

Least Concern

This pollutant priority list is intended to initially rank the pollutants attributable to aircraft emissions based only on their air quality significance. The costs and availability of control technology can then be factored into this ranking to derive regulated standards.

B. Cost of Controls

Implementation of conventional and advanced combustor technologies for large commercial aircraft engines could cost \$1.5-\$2.8 billion over a ten year period. Whether the cost of controls exceeds the air quality benefits is difficult to answer. Data from cost effectiveness studies suggest that aircraft engine controls for THC cost in the order of \$400 per ton of emission reduction and are in line with other air quality control strategies.

CO controls of about \$200 per ton are somewhat higher than other strategies but not necessarily unreasonable. NO_x controls, possible only with advanced combustor technology, cost a projected \$3,400-\$10,200 per ton (two to ten times higher than NO_x controls for other sources). Present aircraft emission levels would not appear to justify these kinds of expenditures.

C. Control Technology

The technology for hydrocarbon controls is effective and can be implemented with relatively minor combustor modifications. CO controls are also effective but to a lesser degree. Limitations on the amount of NO_x emissions allowed influence the degree of CO reductions possible. Available NO_x control technology are less effective than for either THC or CO. High risk development programs are also required to implement the advanced technology combustor concepts for NO_x control. Without any controls, however, aircraft NO_x emissions are projected to double in the next 15 years and reach 11% of the mobile source and over 3% of total source emissions.

D. Implications to Standard Setting

Unless constrained by NO_x regulations, future aircraft will use more efficient engines with higher pressure ratios and combustor inlet temperatures, which will inturn increase NO_x emissions. Difficult policy decisions will have to be made. The regulatory options are:

(1) Allow future engine efficiency improvements accompanied by large aircraft NO_x increases.

(2) Limit future NO_x emission levels, which may constrain engine efficiency improvements.

(3) Force the high costs of undeveloped advanced combustor technologies in order to have both more efficient engines and reduced aircraft NO_x emissions.

While the EPA levels of control proposed in 1978 force NO_x reductions, the International Civil Aviation Organization (ICAO) proposed standards do not. In fact, aircraft NO_x emissions are projected to be greater with the ICAO standards than without. Technology changes which produce effective THC and CO reductions also tend to increase NO_x levels. The ICAO NO_x standards are set at levels where they are not effective constraints to prevent these NO_x increases above uncontrolled levels.

CHAPTER XI

RECOMMENDATIONS

A. Air Quality Assessments

Two important issues of technical uncertainty remain in defining the effect of aviation on air quality.

1. The significance of aircraft THC and NO_x emissions in the atmospheric formation of photochemical oxidants is unknown. Aircraft emissions that result in ambient non-methane hydrocarbon concentrations in excess of the 160 $\mu g/m^3$ air quality guideline have been widely measured and modelled. This guideline is very crude, however, and is no longer recommended by regulatory agencies. Few atmospheric photochemical model applications have focused on airports. The ones used are either dated or produce ambiguous results. Whether or not any pollutant from aircraft "contributes to adverse health or welfare effects" is therefore still a debatable issue and not easily resolved from current scientific information. Continued studies on the characterization of hydrocarbon aircraft emissions and definition of their role as photochemical precursors to oxidant formation should be encouraged.

2. The effect of aircraft emissions on maximum short-term NO_2 concentrations is questionable. The evidence that aircraft could produce hourly NO_2 concentrations in the 0.2-0.5 ppm (400-1,000 $\mu g/m^3$) range is suggestive but certainly not conclusive. The conversion rate of NO emissions to NO_2 in conjunction with atmospheric dilution is not well understood. Also, the short-term NO_2 ambient standard, to be used as a measure of health effects, has not yet been issued.

Studies to clarify or dismiss this potential problem from aircraft should be encouraged.

B. Cost of Controls

The most important cost of control estimates are unfortunately also the most uncertain. Nearly 90% of the projected control costs of $10,000 per ton of NO_x reduced are based on estimates of the maintenance penalties of the complex advanced technology combustors. Costs due to the introduction of immature hardware and decreased combustor durability are involved. Controls for NO_x from aircraft engines should not be considered cost effective unless refinements to these maintenance cost estimates prove the existing estimates are incorrect.

C. Control Technology

A wide range of policy choice exists in the establishment of specific emission standards for aviation sources. The range extends from elimination of all aircraft emission standards to implementation of the maximum control technology. Specific environmental constraints have not been identified since elimination of all aviation standards may not produce identifiable adverse health effects. Conversely, effective control technology is available and the elimination of pollution whenever possible is a desirable goal. The choice of specific aviation emission standards is therefore a policy decision rather than a technical one. Instead of recommending specific levels for emission standards, a general approach is suggested. It is certainly not the only "technically correct" approach possible.

Stringent hydrocarbon aircraft emission standards are suggested. The control technology is available and cost effective. Reductions will not have a drastic air quality effect but should virtually eliminate any contribution of aircraft hydrocarbon precursors to serious oxidant air quality problems. Aircraft engine hydrocarbon reductions would decrease the need for local option controls such as aircraft towing along taxiways or early engine shutdown. A resolution of safety concerns with these local strategies should still be pursued due to potential energy and economic benefits. Certification of such procedures would allow small additional hydrocarbon reductions where deemed necessary because of severe local air quality problems.

Standards for control of CO from aircraft engines should be relaxed or eliminated. There is simply no air pollution problem likely to be solved by such standards. Hydrocarbon standards will also reduce CO emissions so that the potential for future CO problems from aircraft is minimal.

NO_x standards are not now suggested. The difficulty in meeting NO_x control technology, high cost of controls, and the absence of a proven link between aircraft emissions and health and welfare effects are all key issues which should be addressed in the future. Careful planning and long-term management rather than immediate regulatory action is recommended. For example, regulations which force conventional combustor modifications four years prior to requiring advanced combustor technology are of questionable utility. Also the time phasing of advanced technology implementation to the availability of broadened fuel specifications from alternative sources of jet fuel may be possible.

D. Implications to Standard Setting

Several techniques have been explored in this work which have potential usefulness toward establishing standards for non-aviation as well as aviation sources. Continued development and trial applications of these concepts are recommended.

1. The hypothesis decision model offers a structured way of dealing with complex technical issues. Adoption could bring increased use of systems analysis concepts to the process of standard setting.

2. The explicit use of other standard setting techniques in addition to technology based judgements encourages the balancing of all available evidence. Integration of results from several techniques rather than focusing on one individual technique can lead to more effective emission standards.

APPENDIX A - TEST OF HYPOTHESES

APPENDIX A

TESTS OF HYPOTHESES

The "tests of hypotheses" of the Decision Model illustrated in Figure A-1 are presented in detail in this Appendix. Many readers will wish to scan this figure and go directly to the hypotheses of particular interest. Hypotheses H-1 through H-8 are in corresponding sections A.1 through A.8. H-10 is in Section A.9 and H-11 is in Section A.10 (since Hypothesis H-9 did not need to be tested).

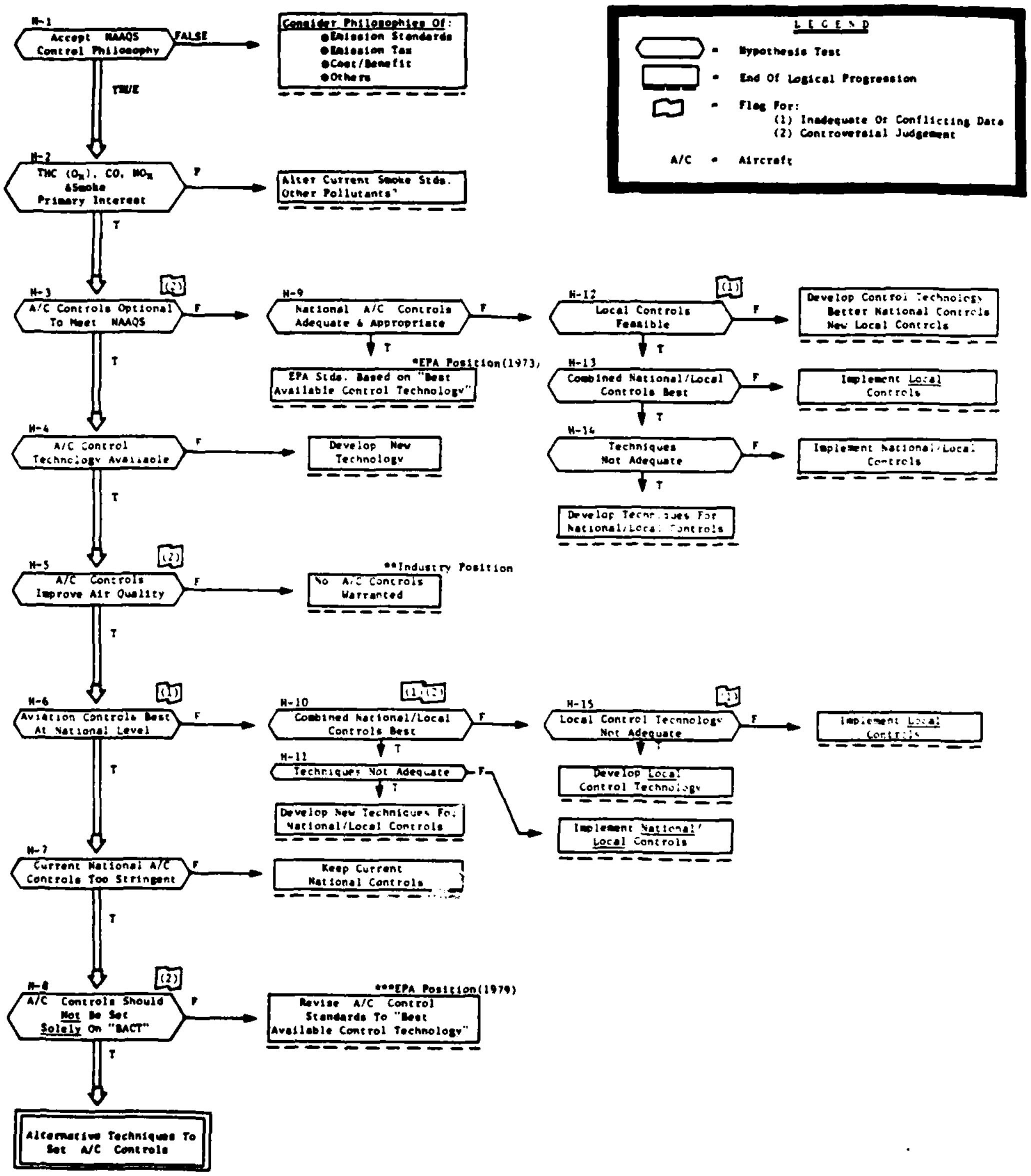
The technical issue, background discussion, data evaluation, findings, and conclusions will be described independently for each hypothesis. A summary of the references with relevant "evidence" is put in tabular form to permit faster scanning of the data and easier updating in the future (except for H-1). The order number of the evidence in these tables has significance. Three different schemes are used:

(1) "Arbitrary Order" (H-1, H-7, H-10).
(2) "Ordinal Rank Order (H-3).
(3) "Reverse Chronological Order" (All other hypotheses).

An arbitrary order is used in H-1 since this hypothesis is assumed (not tested) to be "true". References are listed in an order which best describes the issues. The order of references in H-7 was selected for ease in describing the relationship between control technology and aircraft emission control standards. An arbitrary order was used in H-10 due to the lack of substantive evidence on the issue.

A detailed rank ordering scheme was devised for H-3. This permits an evaluation of both the amount and strength of the evidence. The added complexity was deemed useful due to the regulatory importance of this issue. All other hypotheses are listed in reverse chronological order

CONTROL OF AIR POLLUTION FROM AVIATION: THE EMISSION STANDARD SETTING PROCESS



HYPOTHESIS DECISION MODEL--WITH TEST RESULTS
FIGURE A-1

to permit evaluation of the amount of evidence and the trends as suggested by more recent research and development.

A summary of all evidence order numbers is presented under a "true" and "false" heading within the text describing each hypothesis. This aids evaluation of the amount and sometimes the weight or trends of evidence related to specific issues. It also can be used to quickly locate the evidence on either side of an issue.

The objective of the tabular list of evidence and summary is to explicitly integrate the scientific and technical information into the standard setting process. Documentation includes not only what information was considered but how it was used to make determinations on key issues. Conclusions result from a synthesis of all evidence, not just evidence which may support one point of view or another. Not all parties are expected to agree on the conclusions derived from this evidence or even on the summaries of the evidence themselves. Nevertheless the explicit treatment of all evidence leading to conclusions should ;· cmote a more systematic debate of the technical issues.

APPENDIX SECTION A.1

TEST OF HYPOTHESIS H-1

Hypothesis H-1: "Accept the National Ambient Air Quality Standards (NAAQS) and the U.S. air pollution control philosophy".

Issues:

(1) The U.S. air pollution control philosophy emphasizes attainment of NAAQS as measures of levels to protect the health and welfare of all people in the country. Emission reductions can then be allocated with the goal of achieving these ambient results. Some critics have labeled this system unworkable while others have deemed it economically inefficient.

(2) The accuracy of the NAAQS as measures of health and welfare effects can be questioned. Large differences in human physiological response and the complex mixtures of atmospheric pollutants make the choice of any NAAQS extremely difficult.

(3) In establishing aircraft emission standards, the question is also whether engine emission reductions based on ambient considerations are adequate to prevent high altitude problems. Stratospheric ozone depletion and subtle climatological changes have been deemed possible by some scientists.

Discussion: Alternative air pollution control philosophies are described in Table A-1. Only selected references, rather than a comprehensive list, are shown. Emission standards can be performance standards with quantitative limits or design standards with equipment or process specifications. Air quality standards are based on ambient concentrations to theoretically protect against all health or welfare effects. They usually require compatible emission standards to implement pollution controls. Emission fees or taxes assign an economic cost to pollution emitted into the atmosphere. Cost-benefit controls limit the allowable emissions in proportion to the associated damage.

Most countries are guided by the emission or air quality control philosophies although not always in their "pure" form. For example, Japan uses emission fees to provide incentive to minimize pollution beyond that required by their emission and ambient standards. Common law remedies are available in many countries including the U.S. to supplement statutory law.

The U.S. air pollution control philosophy cannot be considered as an unchanging subject. The basic three step process, ambient standard setting, emission standard setting, and compliance enforcement is extremely complex and controversial. The best scientific data is often very inadequate for important administrative decisions. Congress periodically reviews the Clean Air Act and will do so in 1981 or 1982. The Clean Air Act requires the Environmental Protection Agency (EPA) to review a number of standards and regulations to incorporate new scientific data. The balance among objectives such as environmental quality, energy resource utilization and economic efficiency is a topic of continued debate which includes political as well as scientific considerations.

Even if the U.S. air pollution control philosophy is accepted, the appropriateness of specific NAAQS can be questioned. The process of establishing a set of ambient air quality concentrations to describe the complex biological and physical effects which characterize "health and "welfare" is such an intractable problem that it cannot be done solely on a scientific basis.

The NAAQS do not apply to all environmental concerns related to aviation sources. Upper altitude ozone depletion and climatic effects from flights in the stratosphere have been feared by some scientists. The intensive research to date has not identified the need for aircraft emission reductions beyond those indicated from ambient concerns. Likewise, prevention of significant deterioration (PSD) and hazardous pollutant discharges are major concerns in the U.S. overall air pollution policy but have not been identified as important factors in the setting of aviation emission standards.

Conclusions: The general U.S. air pollution control philosophy and the numerical NAAQS are accepted as they presently exist. They are accepted for the rest of this study as assumptions. A rigorous philosophical treatment of these important issues is therefore beyond the scope of this effort. Attention is instead focused on the emission standard setting process, particularly as applied to aviation sources under the present U.S. control philosophy. These assumptions should be well understood, however, since future changes in the Clean Air Act or National Ambient Air Quality Standards could affect some conclusions and recommendations in this work.

TABLE A-1
TEST OF HYPOTHESIS H-1

ACCEPT NAAQS AND U.S. CONTROL PHILOSOPHY

TRUE (by Assumption)

ASSUMPTIONS	ISSUES	SELECTED REFERENCES	DISCUSSION
A. Accept the U.S. Air Pollution Control Philosophy			
	1. Alternative Philosophies	deNevers (1977) p. 197, 201	Air pollution control programs can be categorized into four philosophies with the following traits:

Philosophy	Descriptor	Cost Effectiveness	Simplicity	Enforceability
(1) Emission Standards	"Cleanest Possible Air"	Very Bad	Excellent	Excellent
(2) Air Quality Standards	"No Health, Welfare Effects"	Good	Poor	Fair
(3) *Emission Tax (Fees)*	*"Market Allocation of Resources"*	*Fair*	*Excellent*	*Excellent*
(4) Cost Benefit	"Acceptable Damage Levels"	Excellent	Terrible	Unknown

Philosophies in "pure form" in the above theory are often in complex "mixed forms" in actual practice.

SELECTED REFERENCES	DISCUSSION
Campbell and Heath (1976) p. 16,17	*The* air pollution philosophies generally practiced throughout the world include air quality standards (AQS), emission standards, or combinations of the two. In 11 countries, the number of air quality standards are greater while in 21 countries, the number of emission standards are greater. The USSR and other eastern European nations rely on AQS with few emission standards. Great Britain has no AQS but many emission standards. The U.S., West Germany, and Canada are based on strong air quality management but also include numerous emission standards.
Mangun (1979) p. 392	A key difference between the U.S. and West German Air Pollution Control Laws is that the U.S. Federal Government can enforce standards if states fail to do so. *These U.S. enforcements have dramatically increased* from 28 (Dec. 1970-Nov. 1972) to 440 (Dec. 1972-Nov. 1974) and to 1477 (Dec. 1974-Dec. 1975). Most Federal enforcement actions are against states who fail to implement their State Implementation Plan provisions.
Corwin (1980) pp. 154-155, p. 157	The Japanese have instituted a complex system of AQS and emission standards based on health effects and not necessarily on available technology. Their Polluter Pays Principal (PPP) is an economic concept which can levy an emission fee even if the source complies with emission standards. The amount of the fee depends on the air quality of the area. The high cost of pollution control has not caused a major shock on Japan's economic growth.
Campbell and Heath (1976) pp. 1-3	The air pollution control philosophies described *above deal with statutory alternatives.* In addition, common law remedies are available to deal with air pollution problems. They include nuisance, trespass, negligence, and strict liability.
Meyer (1972) p. 874	A review of litigations concerning air and noise pollution surrounding airports revealed that courts have traditionally refused common law remedies such as nuisance and trespass. When recoverable, only money damages and not injunctive relief were awarded.

Footnote:
*Comments by this author or conclusions not part of the reference cited are indicated by: ((.....)).

TABLE A-1 (CONT'D.)

TEST OF HYPOTHESIS H-1

ACCEPT NAAQS AND U.S. CONTROL PHILOSOPHY

TRUE (by Assumption)

ASSUMPTIONS	ISSUES	SELECTED REFERENCES	DISCUSSION
	2. Current U.S. Air Pollution Control Philosophy	Costle (1980) p. 846	Despite many accomplishments of the Clean Air Act, it is a troublesome and complex statute. The CAA could come up for Congressional review in 1981 and the possibility exists that it could be gutted and made ineffective in the name of "simplification". The air quality management process involves three complex and controversial steps: (1) The NAAQS Setting: Medical research is inadequate and data to relate the environmental cause to the biological effect is sparse. The question becomes how to set NAAQS on an objective basis when the scientific data will never be good enough. (2) *Emission Standard Setting*: Determination of the right emission limits to reduce or maintain ambient concentrations below the NAAQS levels is amazingly difficult. Huge numbers of calculations involving emission inventories, meteorological dispersion modelling, and ambient monitoring are required. "The system is so cumbersome and problematical that it almost literally forces us to focus on the trees instead of the forest". (3) Compliance with Emission Limits: Problems have been encountered in getting actual compliance rather than "paper" compliance.
		p. 847	There are political, as well as technical, reasons why the CAA may be altered. The number of Political Action Committees (PACs) which lobby to influence Congress has increased threefold from 1974 to 1979. During that time, the corporate PACs jumped from 89 to 949 while other categories of representation remained stable or increased slightly. While some improvements in the CAA and EPA procedures may be desirable, major alterations could also lower the goals of clean and healthful air or delay the air repair process.
B. Accept the NAAQS as Accurate Measures of Levels Which Protect Public Health and Welfare			
	3. NAAQS with Respect to Aviation	Clean Air Act (1977) p. 139	The CAA, Section 231, states that the administrator of EPA shall, from time to time: "...issue proposed emission standards applicable to the emission of any air pollutant from any class or classes of aircraft engines which in his judgement cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health or welfare".
		EPA (1972) pp. 7-8	In this support document to the original federal regulations for control of air pollution from aviation sources, the NAAQS were used as quantitative measures for the protection of "health and welfare". Since aviation emissions are insignificant on global and large regional scales, the NAAQS which inherently apply on a local scale are most appropriate.

TABLE A-1 (CONT'D.)
TEST OF HYPOTHESIS H-1

ACCEPT NAAQS AND U.S. CONTROL PHILOSOPHY

TRUE (by Assumption)

ASSUMPTIONS	ISSUES	SELECTED REFERENCES	DISCUSSION
		Code of Federal Regulations (1980) p. 523	The legislated NAAQS numerical limits and associated averaging times have been quite controversial. As required in the CAA, they are reviewed every 5 years by EPA and are subject to modifications. For the purposes of this work, the current NAAQS are <u>assumed</u> to be accurate measures to protect "health and welfare". The most significant NAAQS values for aviation studies are:

Pollutant	Limit	Averaging Time	Primary Standard (P) or Secondary Standard (S)
CO	10mg/m^3	8 hour avg. - not exceeded more than once per year	P, S
	40mg/m^3	1 hour avg. - " " " " " " "	P, S
PM	150μg/m^3	24 hour avg. - " " " " " " "	S
SO_2	1300μg/m^3	3 hour avg. - " " " " " " "	S
NMHC	160μg/m^3	6-9 am avg. - not to be exceeded more than once per yr.	P, S*
NO_2	100μg/m^3	Annual Arithematic Mean	P, S
O_3	235μg/m^3	1 hour avg. - not to be exceeded more than one day per year	P, S

*(Crude "guideline" for O_3 control -- still in a federal regulation but widely ignored)

ASSUMPTIONS	ISSUES	SELECTED REFERENCES	DISCUSSION
	4. Potential Environmental Problems Not Addressed by NAAQS	Sundararaman (1977) p. 1 p. 14	Environmental concerns regarding aircraft flights in the stratosphere fall into two categories. First, oxides of nitrogen from engine emissions could theoretically reduce stratospheric ozone levels which in turn increases the ultraviolet radiation reaching ground level and perhaps lead to greater incidences of skin cancer. Climatic effects were also feared if the earth's radiation transfer processes were altered from emissions into the atmosphere. With air traffic projections to 1990 and the present understanding of stratospheric effects, there appears to be no imminent threat to the ozone layer. Climatic effects are largely unknown since either cooling due to ozone depletion and stratospheric aerosols or warming due to H_2O, contrails, and NO_2 are possible.
		ICAO-WGA (1980) p. 8	Improvements in stratospheric modelling and new measurements tend to show a substantially <u>smaller</u> effect by aircraft on ozone concentrations than was previously estimated.
		Jones (1978) p. 74	In the stratosphere, concern has shifted in recent years from proposed high altitude supersonic transport (SST) aircraft to the more prevalent subsonic transport aircraft now flying in the lower stratosphere. Until the effects of pollutants in the stratosphere are known with greater accuracy, the establishment of emission standards on a scientific basis is virtually impossible.
		Fay and Heywood (1971) p. 36	Several physical and sociological factors which impact the public's perception of air pollution from aircraft deserve recognition. Airports are generally in the periphery of metropolitan areas and are frequently surrounded by residential communities. Residents may expect and demand cleaner air and other amenities near family residences than would be accepted in central cities. Public reaction to apparent air pollution from airports may be enhanced due to other factors such as noise, fear of crashes, odors, and ground traffic. Economic benefits of the airport may be important to the city as a whole yet nearly invisible to nearby residents.

APPENDIX SECTION A.2

TEST OF HYPOTHESIS H-2

Hypothesis H-2: "Hydrocarbon compounds (for oxidant control), carbon monoxide, oxides of nitrogen, and smoke are the pollutants of primary interest for aviation emission standard setting".

Issues: Due to the vast number of chemical compounds which can be found in the atmosphere, air quality assessments must focus on a reasonable number of pollutants. A comprehensive study of all possible pollutants of environmental interest would divert attention from the more important species. The function of this hypothesis is to document how and why certain pollutants from aviation sources were selected for detailed evaluation in this study.

Discussion: Civil aircraft engine emission standards have been established to limit THC, CO, NO_x, and smoke levels. SO_x, PM mass emissions, trace elements, carcinogenic materials, and odorous compounds in aircraft emissions have been discussed in the literature but not limited by aircraft standards.

Data Evaluation: A review of over 200 documents listed in the References resulted in a list of 40 sources which are useful in narrowing the list of pollutants for primary attention. References were rank-ordered in reverse chronological order as shown in Table A-2. Because of the relatively uncontroversial nature of this hypothesis, a more elaborate ranking scheme was not deemed necessary for this hypothesis. After an evaluation of this hypothesis, the wording of the original H-2 in Figure V-1 was modified to show that THC limitations are intended to control O_x levels and that smoke should be included as a pollutant of interest. To avoid confusion, this revised wording is used in the findings below and throughout this Appendix.

Findings: Studies from Table A-2 used to test hypothesis are shown below:

	True (CO, THC, NO_x and Smoke are of prime concern)	False
CO:	2,5,15,18,20,23,24,25,26,36, 37	1,7,8,16
THC(O_x):	1,2,5,7,9,11,13,15,18,20,23, 25,26,34,36,37	
NO_x:	1,2,5,7,9,18,20,23,24,25,26, 31,34,37	15,36
Smoke:	1,2,3,5,18,19,24,27,28,32,38, 39,40	10,20,22,29,30
PM:	5,7,8,9,15,25,26	17,18,31,33,34,37
SO_x:	1,6,7,15,24,25,26,31,36,37	
Carcinogenic Potential:	4,12,14,32	21
Odors:	16,31,36,37	28,35
Trace Elements; Others:	4,12,37	

The fact that the EPA aircraft engine emission standards includes CO, THC, NO_x, and smoke suggests that these pollutants deserve primary interest unless a significant amount of conflicting data is found. Emphasis on these pollutants is supported by the number of "true" studies above. The significance of carbon monoxide has been questioned by several recent studies but too few to justify elimination from further study. Hydrocarbons are clearly implicated. Oxides of nitrogen from aircraft were deemed negligible by two older reports but not by the newer ones. Exclusion of pollutants such as carcinogenic materials does not mean that they are of no future concern but simply that the current data are too weak to now consider such materials in the aviation standard setting process.

The significance of aircraft smoke is more questionable than the gaseous pollutants described above. While most of the early concern with aircraft air pollution dealt with visible smoke (and odors), the control technology has proven to be very effective. The references listed in the "false" category claim the problem has been completely solved. Older turbojet engines have been replaced with newer "smokeless" turbofan engines in virtually all civil but not all military aircraft. The EPA emission standards have been less controversial for smoke than for the gaseous pollutants. For this reason, smoke was not part of the original Hypothesis H-2 in Figure V-1.

However, after a consideration of all data, Hypothesis H-2 was modified to include smoke. The number of references in the "true" category exceed the number in the "false" category. In addition, smoke may be of future interest because of the potential for changes in fuel characteristics and engine designs. Jet fuels derived from alternate sources such as shale oil will have higher aromatic contents and will burn with more smoke (see Reference 3 in Table A-2). Also, the trend to higher pressure ratio engines will make the job of keeping combustors "smokeless" more difficult.

References are evenly split concerning the significance of particulate matter from aircraft. However, most of the references in the "true" category have a low rank order in Table H-2 which indicates a trend toward later research concluding that particle mass emissions from aircraft are not a problem. Those that are in the "false" category mostly suggest a localized soiling problem from aircraft. Soiling problems have not been reported since 1973 and may have disappeared with implementation of the "smokeless" turbofan engines. Consequently, there appears to be little need to regulate aircraft engine emissions on a particle mass basis beyond the current regulations on a smoke basis.

No evidence could be found which suggests that oxides of sulfur from aircraft are of concern. A significant carcinogenic potential in soot from aircraft was alleged in one Russian article in 1972. Four other references suggest that the amount of carcinogenic material is so low as to be relatively unimportant. There appears to be inadequate evidence to draw firm conclusions.

Odors around airports were the subject of public complaints in several references. However, there appears to be no way to measure or control the responsible chemical compounds. Public interest and concern has not been widespread enough to stimulate serious scientific study of odors from aircraft. Few isolated studies dealing with trace elements, nitrosamines, and other compounds in the aircraft exhaust products were found. No other areas of environmental concern from aircraft emissions are evident.

Conclusions: The pollutants of primary interest in the emission standard setting of aviation related sources are THC (because of the relationship to photochemically produced oxidants), CO, NO_x and smoke. Smoke was not part of the original model hypothesis since the present EPA aircraft engine emission standards for smoke are less controversial than those of gaseous pollutants. Smoke emissions were added to this study since they may be more difficult to control in the future. Higher compression ratio engines and fuels with higher aromatic contents (such as shale oil derived fuels), if adopted in the future, mean that improved technology to keep a "smokeless" exhaust will be needed. There is currently insufficient scientific evidence to indicate that aviation related pollutants, other than those in this hypothesis, are of environmental concern.

TABLE A-2
TEST OF HYPOTHESIS H-2

$THC(O_x)$, CO, NO_x, AND SMOKE ARE POLLUTANTS OF PRIMARY INTEREST

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
1.	Boubel (1980) p.	THC, Smoke: Warrants highest priority. NO_x: Needs more study. SO_x: Not a serious problem from aircraft.	CO: No serious problems.
2.	Clewell (1980) pp. 1-8	NO_x, THC, CO: Aircraft engine catalytic combustors and Variable Geometry Combustors are in advanced development phase. Smoke: Combustor smoke formation, burnout, and fuel additive mechanisms are being studied. O_x: Atmospheric reactivity from shale oil derived fuels is being studied.	
3.	Borger (1980) Conference Presentation	Smoke: Controls will be more difficult if switch is made to fuels from non-conventional sources with higher aromatic contents.	
4.	Robertson (1980) p. 261, 266	Nitrosamines: None found in exhaust measurements. Carcinogenic Potential: Less than 1% organic matter emitted was found absorbed on particulate matter.	
5.	Sundararaman (1979) p. 109	THC: Since O_3 is a regional problem, HC from aircraft cannot be considered in isolation from other sources. CO: *Intense activity of aircraft near terminals may cause "hot spots".* NO_x: The problem may be quite local. PM, Smoke: Emissions do not appear to be a problem except for visibility around airports.	
6.	Kawecki (1978) p. iv	SO_x: EPA concludes that the air quality benefits of any control of any mobile source type are likely to be small. Extremely large control costs would also be involved. Consequently, controls of sulfur bearing compounds from mobile sources, *specifically* motor vehicle and aircraft engines, are not recommended in this report to Congress.	

Footnote:
*Comments by this author or conclusions not part of the reference cited are indicated by: ((.....)).

TABLE A-2 (CONT'D.)

TEST OF HYPOTHESIS H-2

THC(O_x), CO, NO_x, AND SMOKE ARE POLLUTANTS OF PRIMARY INTEREST

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
7.	Naugle (1978)	THC, NO_x: A study of aircraft at 10 Air Force bases suggests that HC and NO_x are the pollutants of greatest interest when compared using the EPA Pollutant Standards Index. PM, SO_x: ((See comments at right)).	CO: Levels of CO, PM, SO_2 reach only about 2% of the NAAQS at 5 km from the runway centers and then only in modelled "worst case" meteorological conditions.
8.	Woods (1978) p. 52	PM: Elemental analysis of aerosols in an area of heavy aircraft traffic leads to the weak suggestion that aircraft exhaust contributes to the atmospheric aerosol character but levels are below health standards.	
9.	Bach (1977) p. 215	THC, PM, and NO_x: Dispersion modelling of *Honolulu Airport* indicates that these pollutants are of prime concern.	CO: Levels of CO are predicted to be well below ambient standards.
10.	Klarman (1976) p. 8		Smoke: Smoke from commercial aircraft is not a problem due to an aggressive retrofit program to install "clean" combustors.
11.	Conkle (1975) p. 10	THC(O_x): About 150 hydrocarbon compounds were identified with jet exhaust products and include various olefins, diolefins, aromatics, and other reactive constituents.	
12.	Fordyce (1975) p. 721	Carcinogenic Potential: The trace carcinogenic material appears negligible but is not well understood. Trace Elements: Of 49 elements sought, only 10 were detected with only aluminum, titanium, and barium above 0.1 ppm. Concentrations from airports are about an order of magnitude below those of typical urban levels.	
13.	Groth (1975) p. 1137	THC(O_x): The reactive portion of gas turbine exhaust, olefins, aromatics, and oxygenated derivatives, ranges from 70% at idle to nearly 100% at high power. ((The assumption in dispersion models that all aircraft HC emissions are in the NMHC category is therefore reasonable)).	
14.	EPA (1974) p. xiv., p. 44	BaP: Control of Benzo(a)pyrene(BaP) as a common surrogate for Polycyclic Organic Matter (POM) is not now warranted. ((Even if warranted, standards would not appear to include mobile sources since stationary sources account for 97% of the nationwide BaP emissions)). Technology for control of BaP from aircraft engines is highly uncertain.	
15.	Bastress (1973) p. 815	PM, SO_2: ((See comments at right)). THC, CO: Concentrations from aircraft may be near ambient standards.	NO_2(Annual Average): Concentrations are well below standards for NO_2 levels on an annual basis, SO_2 and PM.

TABLE A-2 (CONT'D.)
TEST OF HYPOTHESIS H-2

$THC(O_x)$, CO, NO_x, AND SMOKE ARE POLLUTANTS OF PRIMARY INTEREST

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
16.	Mellor (1973)	Odors: Aircraft engine odors are similar to those from Diesel engines.	CO: Levels around aircraft ground operations and maintenance should not produce carboxyhemoglobin levels over 1-2% saturation and are lower than smoking 1 pack of cigarettes per day.
17.	Rote (1973) p. 22		PM: Particulate matter emission densities from aircraft are higher than nearby automotive roadways. The soiling index is greater within the Chicago O'Hare Airport than the surrounding areas. ((Not all commercial aircraft had "smokeless" combustors at this time.))
18.	EPA (1972) p. 508	THC, CO, NO_x: Levels from aircraft are of concern on local scales but not on global or large regional scales. Smoke: Smoke from aircraft causes significant reductions in visibility and is a cause of widespread citizen complaints.	PM: While measurements by Hi-Vol sampling show little variation between downtown and airport areas, dispersion modelling at 4 major airports indicates PM due to aircraft could exceed the secondary NAAQS.
19.	George (1972) p. 508	Smoke: A California law to limit visible contaminants from aircraft to be effective January 1, 1971 was pre-empted by the Federal CAA amendments effective 1 day earlier.	
20.	Sawyer (1972) p. 5, 10	THC, CO, NO_x: Aircraft produce a small but significant and increasing contribution to air pollution.	Smoke: The concensus of manufacturers is that the gas turbine engine smoke visibility problem has been solved.
21.	Shabad (1972) p. 153		Carcinogenic Potential: Soot from aviation engines contain benzo(a)pyrene and has been shown to produce malignant tumors on the skin of mice.
22.	Bristol (1971) p. 85		Smoke: The technology exists for smokeless aircraft engines.
23.	Filippini (1971) p. 207	THC, CO, NO_x: Aircraft engine controls are urged based on emission levels which are in the order of thousands of tons per year.	
24.	Parker (1971) pp. 132-139	CO, NO_x: Ambient measurements at Heathrow Airport, London, indicate that levels from aircraft are low but can be detected above background. SO_2: Directional samplers indicate lower SO_2 levels in air parcels passing over the airport.	
	p. 124	Smoke: Many complaints of smoke deposits from aircraft were received.	

TABLE A-2 (CONT'D.)
TEST OF HYPOTHESIS H-2

$THC(O_x)$, CO, NO_x, AND SMOKE ARE POLLUTANTS OF PRIMARY INTEREST

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
25.	Platt (1971) p. 17	$THC(O_x)$, CO, NO_x: Dispersion model analysis indicates that predicted concentrations compared to NAAQS are significant in airport areas of public access. SO_x: Levels from aircraft are not deemed important. PM: Levels from aircraft are not deemed important from health aspects.	
26.	Raney (1971) p. 639	THC, CO: Large airports have roughly the same emission densities as urban areas. NO_x: Emissions from aircraft are small but will increase 3 fold in 10 years. SO_x: All transportation only account for 2.4% of the national emissions and aircraft are only a small part of that percentage. PM: All transportation only account for 4.22% of the national emissions and aircraft are only a small part of that percentage.	
27.	Westfield (1971) p. 229	Smoke: Pilots have reported reduced visibility in vicinity of airports.	
28.	U.S. Senate (1970) p. 3	Smoke: Congressional subcommittee testimony by the Secretary of Transportation states that aircraft smoke and odor draw considerable public attention and objection.	Odor: ((See comments at left)).
29.	Greathouse (1970) p. 24		Smoke: The turbofan engine will replace the turbojet engine for all aircraft (except supersonic transports) and will eliminate the smoke problem.
30.	Linden (1970) p. 21		Smoke: Smoke can be lowered to below visible levels without engine decrements but the trend toward higher pressure ratio aircraft engines will make the job more difficult.
31.	Sawyer (1970) p. 64 p. 65	NO_x: When compared to automobiles, NO_x and PM are the most important pollutants from aircraft on a grams of pollutant per kg fuel basis. SO_x: Aircraft emissions produce negligible amounts. Odor: Odors are noticeable near airports but little is known about measurement techniques.	PM: ((See comments at left)).
32.	Durrant (1969) p. 61	Carcinogenic Potential: Negligible components result from aircraft. Smoke: Smoke is now the major pollutant from aircraft but can be controlled.	
33.	George (1969) p. 849		PM: A soiling problem exists around airports.

TABLE A-2 (CONT'D.)

TEST OF HYPOTHESIS H-2

THC(O_x), CO, NO_x, AND SMOKE ARE POLLUTANTS OF PRIMARY INTEREST

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
34.	Hochheiser (1968) p. 6	THC, NO_x: While aircraft emissions are less than 1% of the New York urban emissions, they produce about the same emission densities for HC, NO_x, PM. (Airport densities are higher for aldehydes, lower for CO.	PM: ((See comments at left)).
35.	Lozano (1968)		Odors: Odor dilution thresholds are largest for turbofan engines and at idle power settings.
36.	HEW (1968) p. 6, 21	THC, CO: The gaseous pollutants of primary concern in the exhaust of both turbine and piston engine aircraft are CO and HC. Emission densities in 1967 are about the same as surrounding urban *areas for DCA and LAX airports; densities* are about half for the JFK airport.	NO_x: Airport emission densities are only 7% to 50% of the surrounding urban areas.
	p. 3	CO: By 1980, the CO from aircraft is projected to be 3-5% of the Los Angeles county emissions versus the present contribution of less than 1%.	
	p. 8	Odors: There is an absence of knowledge concerning the chemistry of odors from aircraft. Some information from diesel ordor research may be translatable in the future.	
	p. 7	SO_x: Since residual sulfur impurities in aircraft fuels is very small, SO_x is only a minor concern.	
37.	Dix and Bastress (1968) p. 10	SO_x, Lead: Standards could be imposed through fuel specifications but are totally unnecessary due to low levels from aircraft.	
	p. 9	Odors: Odors *from aircraft engines are noticeable* but approaches for control do not exist.	
	p. 13	THC, CO, NO_x: The aircraft exhaust emissions of primary concern are *concluded to be* HC, CO, NO_x *and* PM.	PM: ((See discussion at left)).
38.	McDonald (1962)	Smoke: When aircraft employ water injection to augment thrust on takeoffs, dense dark smoke fills the exhaust wake, reducing visual ranges to as little as a few hundred feet. ((The number of turbojet engine aircraft currently using water injection is quite small)).	
39.	Appleman (1956)	Smoke: Smoke particles and hydroscopic nuclei can result in serious deterioration of visibility over airfields during calm winds and high humidity conditions.	
40.	Cladman (1956)	Smoke: Visibility over the Goose Bay Airport dropped from 5 miles to 1 mile or less when 17 aircraft landed within a 2 hour period. Visibility in surrounding areas was unchanged.	

Footnote

*Comments by this author or conclusions not part of the reference cited are indicated by: ((.....)).

APPENDIX SECTION A.3

TEST OF HYPOTHESIS H-3

Hypothesis H-3: "Airport controls are optional to meet the National Ambient Air Quality Standards (NAAQS).

Issues: The question is if aircraft must be controlled to meet mandated NAAQS levels, or if they are one of many alternative sources which could be controlled to meet environmentally acceptable levels.

Discussion: The Clean Air Act Amendments of 1970 (Section 231) directs the EPA administrator to set aircraft emission standards according to public health and welfare requirements and limited by aviation safety considerations. National Ambient Air Quality Standards were established as a measure of these public health and welfare requirements. In a report to Congress in 1972, the administrator concluded that the evidence at that time indicated that aircraft emission controls were necessary to limit localized "hot spots" surrounding airports which may exceed the NAAQS levels. Aircraft engine emission standards were consequently promulgated in 1973. This action also stimulated many studies involving ambient measurements and dispersion modelling.

Data Evaluation: Approximately 40 references were found to provide some evidence which tends to support or refute Hypothesis H-3. A meaningful data comparison of ambient concentrations from all studies could not be done due to vast differences in airport emission strengths, pollution backgrounds, spacial variations and temporal averaging of the data. Instead, the conclusions of the authors and only key data are compared in Table A-3. Page numbers are indicated for ease in verifying or clarifying all conclusions shown in this table.

An ordinal ranking scheme was devised so that the sources of all evidence could be weighed from the strongest to the weakest. Note that this is <u>not</u> a ranking of the overall scientific merit of these studies. Instead, the relative importance toward only this hypothesis is considered. A study which is highly ranked in this hypothesis may be lowly ranked or not even shown in another hypothesis. Works with a common data base are given a common ranking such as a 6a and 6b.

The criteria used to rank the studies in this H-3 hypothesis are as follows:

1. <u>Type of Study</u>

   -Overall Assessment (with several techniques, below) — Strongest Evidence
   -Ambient Measurements + Modelling
   -Ambient Measurements
   -Air Quality Modelling
   -Emission Analyses — Weakest Evidence

2. <u>Scope of Study</u>

   -Many Airports Considered
   -One Airport or Aviation Source Considered

3. <u>Duration of Study</u>

   -Long Term, Over 6 Months Data
   -Short Term, Less than 6 Months Data

4. <u>Vintage</u>

   -Post 1973 (First A/C Standards)
   -Pre 1973

Criteria #1, Type of Study, was given greater weight than the remaining three criteria of roughly equal weight.

<u>Findings</u>: Studies from Table VI which supply evidence to evaluate Hypothesis H-3 are shown on the following page. Some studies are listed in more than one column when evidence supports different conclusions.

	True (Aircraft controls are optional to meet NAAQS)	Marginal*	False
CO:	1,2,4,5,6,7,9,13,14,16, 17,18,19,20,21,22,23,24, 26,28,29,30,31	12,15,19,25, 27	8,11
NMHC(O_x):	22,29	1,4,6,9,10,11, 14,15,16,21,24, 25,27,32	8
NO_2:	1,3,6,8,9,11,14,19,22, 29	1,2,4,5,8,15,16, 21,25	10,11,32

This analysis clearly shows most evidence supports a "true" hypothesis outcome for CO. Both the [illegible] of the evidence and the weight (indicated by low ordinal rankings) of the evidence strongly point to this finding. Universal agreement of these past studies cannot be expected due to scientific differences in measurement techniques, modelling methods plus variations in professional opinions.

Most of the evidence for non-methane hydrocarbons (NMHC) is in the "marginal" column. This suggests that a scientific resolution of this hypothesis is not now possible. The problem in this case is that the NAAQS for NMHC levels has been specified as 0.24 ppm in the Federal Register but is treated as a "guideline" rather than a standard. The reason is because health and welfare effects do not result directly from NMHC levels but only when they are chemical precursors which result in high oxidant levels. Many studies summarized in Table A-3 have pointed out that not only airports but many other sources cause widespread

*Marginal: Category of evidence which suggests environmental concern although a NAAQS is not violated. Some reports suggest that the NMHC "guideline" may be violated (but is only a crude indicator of NAAQS O_3 violations). Others suggest concentrations near the proposed short term NO_2 NAAQS are possible.

exceedances of the 0.24 ppm guideline levels. Such studies were classified as marginal since they have not shown that NAAQS violations for O_3 have resulted. Also, the present NAAQS NMHC Guidelines are not being used by EPA as an unenforceable concept. The null hypothesis of "true" is accepted because of the lack of evidence to the contrary.

The evidence for NO_2 almost equally falls into a "true" or "marginal" category. There is little support for a "false" determination (NO_2 violations). Airport concentrations below the annual average NAAQS have generally demonstrated for current emission levels but not necessarily for future levels. There is as yet no short term NAAQS for NO_2 although one is required by the Clean Air Act Amendments of 1977. Levels in the 0.2 to 0.5 ppm range are under consideration by EPA. Extrapolation of ambient measurement data and some modelling data suggest airports may cause "hot spots" close to these levels. Until the short term NAAQS for NO_2 is promulgated and the current suggestive data is improved, the weight of all evidence is found to support a "true" rather than a "false" determination.

Conclusions: The conclusion from a synthesis of all evidence reviewed and presented in Table VI is that a "true" determination should be assigned to Hypothesis H-3. Aircraft emission standards should be considered an optional, but not necessarily essential, component of strategies to meet national ambient air quality standards. This conclusion is well supported in the case of CO but somewhat tentative for THC since there is no enforceable NAAQS for NO_2 since the short term standard has not been promulgated.

The above conclusion suggests that standard setting techniques other than those which force the maximum emission reductions may be appropriate for aircraft. Although treated separately in the Clean Air Act, aircraft should not logically be isolated from other national air pollution control strategies. The determination that aircraft could be a contributor but are not solely responsible for health and welfare effects suggests that emissions standards for aircraft might be established by techniques other than the best available control technology. Other techniques are described in Chapter VIII of this work.

TABLE A-3
TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

Ordinal Rank (Strongest Evidence First)	Category* of Study	Reference/ Section(s) or Page(p)	True	Marginal***	False
1	OA	Yamartino, et al. (1980)	((This work presents data from recent measurement studies, reviews many previous measurement and modelling studies, and has received an extensive interagency review. *It was therefore given the highest ranking.*))		
			Overall Conclusions are:		
		p.20	CO: Recent studies suggest the maximum hourly concentration *from* airports *are* about 5ppm *in areas* where the NAAQS (of 35ppm) are appropriate.	NMHC(O_x): Despite the lack of any *NAAQS or direct* health threat, control may be desirable to reduce emissions (1-3% of AQCR total) and odor problems.	
		p.20 p.69	Annual NO_2: Data from airport studies *indicate* levels will be confined to 10-20% of the 0.05ppm NAAQS.	Hourly NO_2: Both extrapolation *of cumulative* frequency distributions of measured airport data to the 99.99% *probability level as well* as dispersion modelling indicate the possibility of airport concentrations *in the 0.2 to 0.5ppm range.*	
			Individual Airport Studies:		
		p.6	Dulles International Airport - 150 individual aircraft taxi and 50 takeoff events were measured during a 1 year period with up to three towers.		
		pp.28-32 p.69	CO,NMHC,NO_x: Regional impacts very low from all *aircraft* including the Concorde.	Hourly NO_2: NO_2 *concentrations over 0.2ppm* were not observed but levels with a once per yr. probability of ≈0.3ppm can be conservatively extrapolated.	
		p.120	CO: Concentrations *within 60* meters should not exceed 6ppm even with 100 aircraft taxis per hour.		
		p.6	Washington National Airport (DCA) - Joint EPA and FAA project to measure CO, NO, and NO_x for *2 months with 4 stations.*		
		p.83	*CO:* Extrapolation of measured concentrations made 300 meters behind aircraft queuing area provides estimate of max. hrly. value *of ≈5 ppm.* This is consistent with updated modelling at LAX.		
			Los Angeles Int. (LAX) Airport *Queuing* Study - 1 week of CO data with 2 monitors.		
		p.139	CO: *The addition of* initial aircraft plume size and height *in a* simple model is compared to recent measurements.((Large over estimates in *1970's LAX modelling used in* standard setting may be due to inadequate initial dispersion parameters))		
		p.6	Williams AFB Study - USAF project with 1 year of paired measurement and modelled data of CO, NMHC, NO, NO_x, and scattering *coefficients.*		
		p.155	CO: The highest CO hourly concentrations of 0.18ppm *modelled and* 0.13ppm modelled are well below the NAAQS.		

Footnotes:

* OA = Overall Assessment
AQ = Air Quality *Measurement*
DM = *Dispersion* Model
PM = Photochemical Model
EA = Emission Analysis
CA = Control Alternative

** Comments by this author or conclusions not part of the *reference* cited are indicated by: ((.....)).

*** Marginal: Category of *evidence* which suggests *environmental* concern *although a* NAAQS is not violated. Some reports suggest that the NMHC "guideline" may be violated (but is only a crude indicator of NAAQS O_3 violations). Others suggest *concentrations near the proposed short term* NO_2 *NAAQS are possible.*

TABLE A-3 (CONT'D.)

TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL	FALSE
2	OA	ICAO(1980)	This report is by the Working Group "A" of ICAO with members representing Canada, France, Japan, and the United States. It is based on a review of 10 monitoring and 9 modelling studies of airports around the world.		
		p.82 p.32	CO: Concentrations at airport boundaries range from 1 to 4ppm for hrly. concentrations and modelled "worst case" meteorology. Measurements indicate that levels at airport boundaries are low compared to travel in city traffic, smoking, and the US NAAQS.	NO_2: The "worst case" levels of NO_x from model results are less than 0.12ppm at ½km from aircraft sources. The fraction of NO_2 in this NO_x prediction is poorly understood.	
3a.	OA	Jordan(1979) p.123	NO_2: Based on past monitoring and measurement studies and unless emission levels are increased substantially, violations of the World Health Organization standards (.10-.12 ppm hrly. avg., not to be exceeded more than once per mo.) would be very unlikely. From modelling, max. hrly. NO_x from an airport is 30-50% of a 100 megawatt power plant meeting the New Source Performance Standards.		
3b.		Jordan(1977) p.27			
4	OA	Cirillo(1975)	Based on extensive dispersion modelling of the Hartsfield Airport and metropolitan Atlanta, the following conclusions were made.		
		p.87 p.98	CO: The maximum hrly. concentration within the airport is ≅ ½ of the NAAQS and much less outside the airport. This was judged to create no regional problems.	NMHC: Airport sources are equivalent to the Atlanta central business district in emission density and air quality impact near the airport (within 14 km).	
		p.105 p.110		NO_2: The worst case hrly. levels from the airport are .25ppm at 6 km. The summer hrly. average is predicted as 0.03ppm at 6 km.	
5	AQ	EPA OAQPS(1980)	This is the EPA background report of the recent Washington National Airport study also described above in Yamartino(1980).		
		p.1	CO: At no time did measured levels approach the NAAQS, except in a snowstorm. CO is projected to be 1ppm higher at the "downwind" observation site dur-	NO_2: Measured hrly. data are insufficient to show a correlation between either wind or number of aircraft take-offs.	

TABLE A-3 (CONT'D.)
TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL	FALSE
6a.	AQ	Yamartino, Conley(1980)	Continuous hrly. data of both measured and modelled concentrations at 5 stations for 13 months on Williams Air Force Base (Phoenix, Az.) make *this study one of the most comprehensive around any* airport. Conclusions are:		
		Fig.5	CO,NO_2: Cumulative frequency distributions indicate levels are small when compared to the NAQQS. Model performance is acceptable when urban background is substracted. Maximum hrly. levels within 200 meters of aircraft operations are 1-9 ppm for CO and 0.2ppm NO_x(modelled data).	NMHC: Widespread excursions above the 0.24ppm "guideline" were both measured and modelled.	
6b.	AQ	Sheesley(1980)	This report describes the ambient measurement portion of the above study.		
		viii	CO, NMHC: Even though this site was selected because it was 60 km *distance* from Phoenix with a high ratio of aircraft emissions to urban background, hrly. levels due to aircraft and levels due to background were difficult to distinguish.	NO_x: NO_x emissions from these aircraft are low compared to civil aircraft so no conclusions concerning civil airports can be made.	
7	DM	Yamartino, Rote(1979)	Based on updated models applied to LAX, and ORD (O'Hare) Airports, the following conclusions were made. (While still Gaussian in nature, these updated models have different emissions data and dispersion coefficients than used in studies at airports in the early 1970's upon which the 1973 aircraft standards were set.)		
		p.131	CO: Max. hrly. concentrations due to airport sources were less than 10% of the NAAQS in and around the airports.		
8	OA	Lorang(1978)	This EPA review of past airport impact studies concluded that:		
		p.47 p.48	NO_2: No annual violations are judged to occur.	Short Term NO_2: The NO to NO_2 conversion remains an unresolved issue and is important due to the considered NAAQS for hrly. NO_2 levels.	CO: Aircraft violations of the NAAQS were measured at LAX and DCA. Aircraft violations of the NAAQS were modelled at ORD. (Yamartino (1980), Section 3.2.1, points out that the Lorang conclusions were based on measurements in terminal areas where NAAQS do not apply.)
		p.48 p.59			NMHC(O_x): Violations of the NAAQS for O_3 are quite possible since airports emit thousands of tons per year and 59% of the aircraft operations are within areas of the U.S. with oxidant violations.

TABLE A-3 (CONT'D.)

TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL	FALSE
9	AQ	Williams (1980)	This study represents the most comprehensive air quality monitoring around an airport in the United Kingdom. Six months data at 1 fixed site and 17 weeks data at 6 rotating sites were collected at Gatwick Airport (London).		
			CO, NO_2: No concentrations above the U.S. NAAQS were measured. A proposed second terminal is judged to be no problem.	NMHC: Measured levels exceed the "Guidelines" of 0.24ppm almost 50% of the time.	
10	PM	Duewer(1978)	A photochemical Eulerian grid model is applied to the San Francisco Bay area and three civil airports.		
		p.91		NMHC(O_x), NO_2: Airport emissions may cause significant increases in peak O_3 levels of up to 0.003ppm. ((One could argue that since SF is a non-attainment area for O_3, that airport emissions can be significant contributors to the 0.12ppm NAAQS. However, results from this complex model are tentative since they are very sensitive to assumed NO_x/HC ratios of emissions and ambient background.	
11a.	OA	Bastress(1973)	Based on the data in Platt(1971) below, these conclusions were drawn:		
		p.814		NMHC(O_x): ((See comments at right.))	CO, NO_2: Both measured and modelled data from 4 airports indicate concentrations exceeded applicable standards.
11b.	CA	EPA (1972)	This EPA Support Document was issued along with the proposed aircraft standards. It is based heavily on Platt(1971) and Nature(1968) below. Conclusions were:		
		p.5 p.35 p.49		NMHC(O_x): ((See comments at right.))	CO, NO_2: Airports quite likely exert a localized impact on air quality, in excess of NAAQS levels. This is based on emission densities, monitoring and modelling where 13 days/mo. were over the 8 hr. CO NAAQS, NMHC was well above the 0.24ppm Guideline and NO_x levels are comparable to NAAQS levels.
11c.	OA	Platt(1971)	This Northern Research and Engineering Corporation (NREC) Study is based on dispersion modelling at the LAX, DCA, JFK, ORD, Van Nuys and Tamiami Airports.		
		p.19		NMHC(O_x): ((See comments at right.))	CO: Predicted concentrations due to aircraft emissions exceed the NAAQS in the vicinity of major air carrier airports.
		p.19	NO_2: Levels due to aircraft alone do not exceed the NAAQS.		

TABLE A-3 (CONT'D.)
TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL	FALSE
11d.	OA	HEW (1968)	This EPA sponsored study was in response to the requirement in the Clean Air Act for a comprehensive study of the need for aircraft emission controls. Findings were:		
		p.8 p.13		CO,HC, NO_x: Aircraft emissions are small (≃1%) but likely to increase. Airport emission densities are comparable to adjacent communities (within a factor of 2 or 3). The air quality impact is not directly measurable due to the difficulties in separating the airport component.	
12a.	AQ	George(1972)	This paper summarizes the LAX airport study also described below.		
12b.	OA	Lozano(1971)	Air quality measurements of CO (and particulate matter) at 9 fixed and 26 mobile stations were obtained for 5 months. Findings include:		
		p.5 p.7		CO: Average levels in terminal (14-16ppm) and parking ramp (5-10ppm) are higher than in downtown Los Angeles (4-6ppm). Levels on the east side of the terminal (4-10ppm) approach the NAAQS.	
12c.	AQ	LAAPCD (1971)	This report presents measurement data of the LAX study.		
13	AQ	Parker(1971)	Ambient measurements were taken for 6 months at 4 sites, two of which used directional samples to try to determine airport upwind and downwind differences.		
		p.141	CO: Levels exceeded 30ppm only 0.02% of the times and these values were recorded near the terminal. (Where NAAQS may not apply) The airport was concluded to be an insignificant contributor to air pollution problems.		
14	DM	Naugle(1978)	Dispersion modelling of 10 U.S. Air Force bases and surrounding communities was performed.		
		p.391	CO, NO_2: Concentrations beyond several kilometers downwind of aircraft operations were predicted to be less than the NAAQS as measured by the	NMHC: Levels above the Guidelines were predicted.	

TABLE A-3 (CONT'D.)
TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL	FALSE
15	AQ	Thayer(1974)	Measurements and modelling on the DCA Airport at 5 sites over a 6 month period were reported in this study.		
				High levels were observed at the 98th percentile as follows:	
		p.5		CO: Hourly values at one station were 60ppm while others were only ≈10ppm.	
		p.4		NMHC: The 6-9 a.m. observations at 3 stations were 3.0, 3.8, and 13ppm. NO_2: Hourly observations at 3 stations were 0.22, 0.25 and 0.28ppm on the airport. (Data are in this "marginal" column since the airport vs. urban contributions to there concentrations could not be resolved.)	
16	OA	Jordan(1977)	This report includes some analysis of large civil aircraft as well as general aviation aircraft.		
		p.5 p.6	CO: From Platt(1971), aircraft contribute less than 10% of the NAAQS at distances over a few km from the airport.	NMHC: High levels were calculated. NO_2: With all NO_x assumed to be NO_2, levels reach 50% of the NAAQS near runways and only 10% at the airport fence.	
17	AQ	Segal(1978)	Numerous CO measurements were made within the Lakeland, Florida Airport during a special general aviation "fly-in" with over 250 operations per hour.		
		p.79	CO: All observations were less than the NAAQS. Maximum hrly. levels where people might be located were less than 2ppm.		
18	AQ	EPA (1972)	Measurements at the Dade, Collier Training and Transportation Jetport were made over a 6 month period.		
		p.26	CO: An hrly. maximum out of 3,855 observations was 6.5ppm. The overall mean was 2ppm or about at the background level.	O_3: Violations above the old NAAQS of .08ppm were observed. The source of precursors was undetermined.	
19	DM	Thayer(1974)	A dispersion model was applied to Salt Lake City and its International Airport.		
		p.1 p.25	Hourly CO, Annual NO_2: While exceedances of the max. hrly. CO and annual NO_2 NAAQS were predicted with current emissions, none were due to airport emissions.	Maximum 8 hr. CO: One exceedance of the NAAQS level was predicted (but only within the airport where application of the NAAQS is questionable). The conclusion is made that federal aircraft emission standards as well as automotive standards are significant in	

TABLE A-3 (CONT'D.)
TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL***	FALSE
20	DM	Shelar(1978)	Based on dispersion model results for Dulles International Airport (Washington, D.C.) and the EPA Guidelines for Evaluation of Indirect Sources, the following conclusions were made:		
		p.165	CO: The maximum hrly. CO NAAQS would not be exceeded between 1976 and 1995. Exceedances above the 8-hr. NAAQS were predicted at 2 airport locations with 1976 emissions data but not with 1980 through 1995 emissions data (due to ground vehicle emission reductions).		
21	DM	Delsey(1978)	A numerical dispersion model was applied to the Orly and Roissey-En-France Airports (Paris) with the following conclusions:		
		p.107	CO: Levels cannot exceed the U.S. NAAQS.	NMHC: The U.S. NAAQS Guidelines are exceeded over a wide area. NO_2: Annual U.S. NAAQS levels are probably not exceeded.	
22	DM	Koch(1978)	Dispersion model predictions performed for the entire year of 2,000 for a proposed jetport offshore in Lake Erie, Pa. suggest:		
		p.186	CO, NMHC, NO_2: Levels would be well below the NAAQS even within the jetport. The impact to nearby Cleveland is negligible even under lake breeze conditions which tend to restrict dispersion.		
23	DM	Schewe(1978)	Application of an EPA dispersion model to the active Van Nuys Airport with general aviation aircraft indicated:		
		p.147	CO: Violations of the 1 and 8 hr. NAAQS are predicted within 100 meters of some aircraft. ((Application this close is not deemed appropriate)). Concentrations decrease rapidly so that levels beyond 200 meters are below the NAAQS.		
24a.	DM	Bach & Daniels (1977)	A dispersion model was applied to the Honolulu International Airport including commercial aircraft, military aircraft and non-aircraft operations.		
		p.215	CO: Pollutant contributions from aircraft are much less than the NAAQS at the nearest residential areas.		
24b.	DM	Daniels & Bach (1976)		NMHC: Violation of the Hawaii AQS of 0.15ppm is predicted for a number of	

TABLE A-3 (CONT'D.)

TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL	FALSE
25	AQ	AIAA(1980)	Measurement studies of airports in Osaka, Japan; Paris, France; Landvetter, Sweden; and Toronto, Canada are described in this letter and enclosures from the Aerospace Industries Association of America, Inc. to EPA.		
				CO, NMHC, NO_2: While this letter claims these studies demonstrate *emission standards* for aircraft are absolutely unnecessary, the *enclosures* are scientifically unconvincing. They are preliminary documents with some data but little or no findings and conclusions by the investigators. Quality assurance information is missing.	
26	AQ	Bellin(1980)	Measurements of CO levels in the Logan International Airport (Boston) were conducted both outdoors and indoors.		
		p.393	CO: Levels both indoors and outdoord did not exceed the hrly. NAAQS. (Levels over the 8-hr. NAAQS can be projected but not in areas of general public access).		
27	CA	Zinger(1976)	This study compares the potential air quality impact of many unregulated mobile sources (not including aircraft).		
		p.111 p.205		CO, NMHC(O_x): The conclusion was made from rollback methods that lawn and garden implements, outboard motors and occasionally snowmobiles and farm equipment can be significant contributors in the future to exceedances of the NAAQS. ((Aircraft are greater than all these sources.))	
28	AQ	Greenberg(1978)	Measurements of CO were obtained during 20 days of testing at 14 sites.		
		p.24	CO: No violations of the NAAQS were observed. The highest 12 min. averages were 7ppm at the airport perimeter and 20ppm *near* the terminal.		
[illegible]	[illegible]	[illegible](1973)	Emissions from the Heathrow and Gatwick Airports near London were compared to adjacent roadways.		

TABLE A-3 (CONT'D.)
TEST OF HYPOTHESIS H-3**

AIRCRAFT CONTROLS ARE OPTIONAL TO MEET NAAQS

ORDINAL RANK (STRONGEST EVIDENCE FIRST)	CATEGORY* OF STUDY	REFERENCE	TRUE	MARGINAL	FALSE
30	OA	AGARD(1973)	A physician responsible for large numbers of ground staff at the Heathrow Airport makes the following conclusion:		
		p.13-1	There are no indicated serious long or short term effects to health of the staff with respect to poisoning, respiratory irritation, and carcinogenesis. The exception could be ground vehicles in confined spaces. Short term effects such as irritation to the eyes, nose, and throat are common complaints but cannot be regarded as serious. CO: April-September 1970 measurements indicate peak levels of 24ppm on the aircraft side of the terminal and 50ppm on the other ((vehicular)) side.		
31	CA	Pratt & Whitney (1978)	Testimony at public hearings by SAI, Inc. under contract to Pratt & Whitney included:		
		p.9	CO: The ambient impact of aircraft is "insignificant" since it has been shown to be less than 2ppm. EPA proposed in the PSD rulemaking to not consider the impact of sources when they are below levels deemed "insignificant" (later established as 2ppm).		
32	PM	Kitagawa (1977)	The following supposition was presented at an international conference:		
		p.531		NMHC(O_x), NO_2: The origin of the photochemical smog is now proposed to be the exhaust of aircraft flying in the inversion aloft. Improved engine designs and maintenance procedures plus careful selection of air routes are urged.	

Footnotes:

* OA = Overall Assessment
AQ = Air Quality Measurement
DM = Dispersion Model
PM = Photochemical Model
EA = Emission Analysis
CA = Control Alternative

** Comments by this author or conclusions not part of the reference cited are indicated by: ((.....)).

APPENDIX SECTION A.4

TEST OF HYPOTHESIS H-4

Hypothesis H-4: "Aircraft control technology is available".

Issues: Controls must be feasible in the engineering sense and acceptable from the safety standpoint for emission standards to be considered. If such technology is not available, further research is needed prior to setting standards.

Discussion: Basic aircraft exhaust pollutant formation processes are discussed in Chapter VIII. The availability of technology to minimize these pollutant concentrations needs to be addressed prior to setting emission standards. There is no sharp, easily defined, distinction of when these technological concepts are available or not available. Instead, there is an inter-relationship between many different degrees of pollutant control; time periods required for engineering development, test and evaluation; pollutant species for which controls are desired; aircraft engine design configurations; and engine operational design parameters. The function of this H-4 Hypothesis is to describe and generally evaluate if control technology is available by pollutant species. The more specific pollutant reductions feasible by engine class, implementation time, and pollutant specie are the subject of Hypothesis H-7.

Data Evaluation: Full consideration of all engineering data which affect the complex inter-relationships described above are beyond the scope of this work. Comprehensive reviews of such data, including literally hundreds of published and unpublished references have been performed by others. (Jones, 1978; Munt, 1976; Mellor, 1976). Findings and conclusions from these works and others were used to compile Table H-4. Technology shown to be effective (arbitrarily defined as greater than 50% reduction from conventional engine designs) which can be implemented without extensive and high risk development programs is shown in the "true" categories. Since general agreement was found in this data, references were simply put in reverse chronological order. Discussions of aircraft engine design configurations, concepts of emission control, and technologies applied to aircraft engine combustors are presented in the following paragraphs.

Aircraft engines are most generally divided into turbojet, turboprop, and turbofan categories as shown in Figure A-4-1. Turbojet engines derive their thrust by rapid acceleration of a relatively small mass of air. They are best suited for high-flying, high speed aircraft but suffer from low thrust at low air speeds. Turboprop engines derive thrust both from the aerodynamic action of the propeller (roughly 90% of total thrust) and from rapid air acceleration. They have very high propulsive efficiency and are commonly used on small commercial aircraft and cargo military aircraft. Turbofan engines have duct enclosed rotating blades and stationary vanes which produce 30%-75% of the total thrust (Pratt & Whitney, 1970, p. 29). The remaining thrust is from rapid air acceleration. Newer commercial engines are usually "high bypass" types where most of the air through the fan section is immediately exhausted and therefore bypasses the basic engine sections where compression and combustion take place. Greater propulsive efficiency at low altitude results.

A cutaway of a typical turbofan aircraft engine is shown in Figure A-4-2. The combustion chambers or "combustors" are primarily the target of air pollution control technology. With the exception of after-burning engines used in military fighter-type aircraft or civil supersonic transport aircraft, pollutant concentrations are essentially fixed at the combustor exit plane.

A combustor schematic, operational parameters and air pollution control concepts are illustrated in Figure A-4-3. Current engine designs are optimized for operation in high thrust conditions which leads to high combustor inlet temperatures (T_{in}) inlet pressures (P_{in}) and fuel/air (F/A) ratios. The resulting high combustion temperatures are associated with high NO_x and smoke emissions but essentially no THC and CO emissions. Low thrust conditions such as during aircraft idle, or taxi are characterized by relatively low T_{in}, P_{in}, and F/A conditions. Nearly all THC, CO and some of the NO_x emissions come from these aircraft/engine modes of operation. Control technologies are often categorized as high power (for NO_x, smoke) or low power (for THC, CO, and sometimes NO_x). As noted in Figure A-4-3, some of the corrective approaches for CO and THC are the exact opposite as desired for NO_x. Simultaneous control of all pollutants therefore presents technological difficulties. Effective control of THC levels is the least difficult since compounds most rapidly oxidize (see Chapter VIII, Figure VIII-1). Control of CO is possible since it will oxidize if a longer residence time at high temperatures can be maintained. Control of NO_x is the most difficult since the decomposition rates are so slow that the only control is essentially to prevent the initial NO_x formation.

Concepts of emission control technology can be categorized under modified conventional combustors and advanced combustors as previously shown in Chapter VIII, Figure VIII-2. Schematics to illustrate these concepts are presented in Figures A-4-4 through A-4-6 for modified conventional combustors and A-4-7 through A-4-12 for advanced combustors. The availability of these emission reduction concepts is presented in Table A-4.

Findings: There appears to be little technical disagreement of the basic outcome from testing Hypothesis H-4. A summary of references from Table A-4 is as follows:

	True (Aircraft Control Technology Available)	False
THC:	1,2,3,4,5,6,8,9,10,11	
CO:	1,2,3,4,5,6,8,9,10,11	
NO_x:		1,2,3,4,5,6,7,8,9,10
Smoke:	2,4,6,8,9	

Conclusions: The technology to effectively reduce THC and CO emissions from aircraft engines generally exists and can be implemented without extensive and high risk development. Reductions from levels in current production engines of 70% - 90% for THC and 50% - 70% appear reasonable. Smoke emissions are now below "smokeless" criteria for most commercial aircraft.

Extensive and high risk development is needed to implement technology for NO_x reductions simultaneously with THC and CO reductions. This technology involves staged combustor, variable combustor, or catalytic combustor technology and has only been successfully demonstrated in a few experimental studies. The NO_x for CO trade-offs are particularly difficult.

The above conclusions apply only to present jet fuel specifications. Fuels derived from alternative sources, such as shale oils, have characteristics which alter emission levels. Maintaining current emission levels, much less large emission reductions, will be difficult. A switch of this type could necessitate implementation of advanced technology combustors for durability as well as emission reasons.

TABLE A-4
TEST OF HYPOTHESIS H-4

AIRCRAFT CONTROL TECHNOLOGY IS AVAILABLE

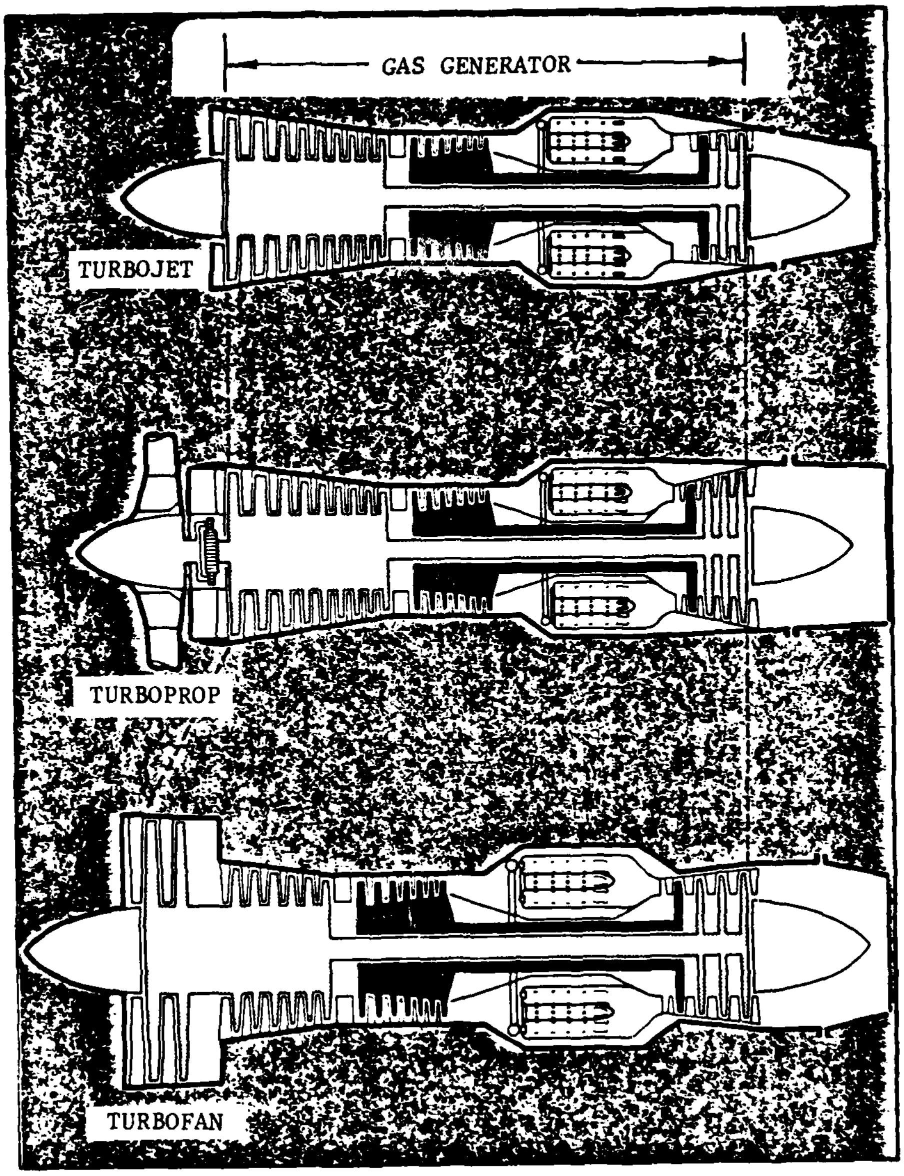
REVERSE CHRONOLOGICAL ORDER	SELECTED REFERENCE	TRUE	FALSE
1.	Mularz, Gleason and Dodds (1979) p. 61 p. 56	THC, CO: Both THC and CO emissions were effectively reduced by all concepts tested in this Low Power Emissions Reduction (LOPER) program. Three concepts were tested: (1) Thermal barrier ("hot wall"), (2) Recuperative cooling (dilution air preheat), and (3) Catalytic converter combustors (see Figure A-4-7 to A-4-9). Reductions of 98% for HC and 94% for CO were seen in these experimental studies.	NO_x: Small increases in NO_x (about 25%) were seen with these LOPER program concepts. Program goals were not to reduce NO_x but to prevent the potential tradeoff of large CO reduction for large NO_x increases.
2.	Pratt and Whitney, 1978 Chart 21, 22 p. 3	THC: Reductions of 80-90% are achievable on some engines. CO: Reductions of 70% are achievable on some engines. Smoke: The technology for control has been demonstrated since current engines meet the low smoke criteria.	NO_x: Engines which effectively reduce NO_x simultaneously with CO and HC are beyond the current production capability.
3.	Jones (1978) p. 80 p. 81	THC, CO: Basic approaches effective for HC and CO reductions are: (1) Increase primary zone residence time. (2) Retard mixing with dilutant air. (3) Increase primary zone equivalence ratio to 1.0 (by engine bleed or fuel scheduling). (4) Improve fuel distribution and atomization. ((See Figure A-4-3))	NO_x: In practice, it is very difficult to simultaneously reduce all pollutants in a single stage combustor. Approaches (1), (2) and (3) for HC and CO are the opposite of effective NO_x controls. Water injection at high engine power effectively reduces NO_x but requires demineralized water flow rates that could be as large as fuel flow rates. Staged combustors with high and low power zones are one way to reduce all pollutants (See Figures A-4-10 and A-4-11). ((Staged combustors involve advanced technology with major development needed. They therefore fall in the "false" category for this hypothesis)).
4.	Jones, Diel, et al. (1978) pp. 32-34	Experimental engine test data in the T-2 and T-4 classes suggest the following improvements are possible without extensive additional development: THC: 91% to 98% reductions were measured on test combustors. CO: 42% to 69% reductions generally measured with one concept as low as 11% (but effective for NO_x). Smoke: Some increases shown with experimental combustors compared to production combustors but optimization to "smokeless" levels is likely without extensive new technology.	NO_x: Extensive additional development deemed necessary for significant NO_x reductions. Test results ranged widely from 10% to 58%.
5.	EPA Support Document, 1978 p. A-6	THC, CO: Effective reduction measures have been demonstrated for the T1, T2, T4, P2 and APU engine classes.	NO_x: Significant reductions have been demonstrated in the laboratory only. Continued NO_x development is needed.

TABLE A-4 (CONT'D.)

TEST OF HYPOTHESIS H-4

AIRCRAFT CONTROL TECHNOLOGY IS AVAILABLE

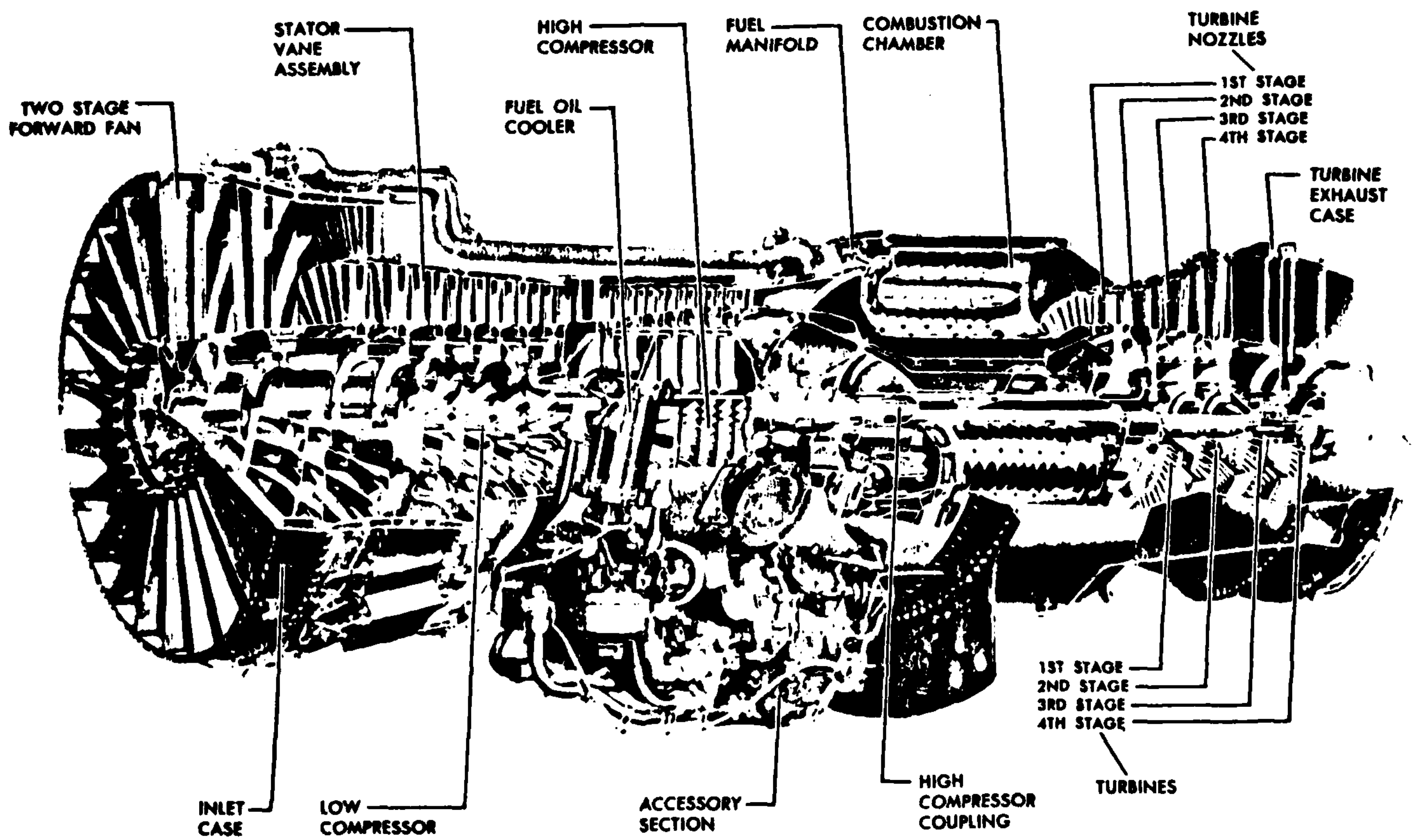
REVERSE CHRONOLOGICAL ORDER	SELECTED REFERENCE	TRUE	FALSE
6.	Mularz (1977) p. 653	THC, CO, Smoke (P-2 Engine Class Only): Substantial reductions were achieved in turboprop engines with reverse flow, prechamber (see Figure A-4-5) and staged fuel concepts. All concepts are advanced and need some further development. The reverse flow concept is recommended as the best candidate. Reductions of 98% for HC, 85% for CO and 69% for smoke were measured.	NO_x: No change or a slight increase resulted with these three concepts. The recommended reverse flow concept had a 17% increase.
7.	Mellor (1976) p. 115 p. 118		NO_x: Pollutant formation in terms of 5 characteristic times is presented. Reductions can be considered a trade-off between NO_x and CO since if the CO control standard is met the HC levels are very low. Experimental results suggest minor modifications will at best produce a 50% NO_x and CO reduction. Water injection is considered impractical due to logistics and safety requirements.
8.	Munt (1976) p. iv	The EPA technical staff made the following assessment based on data supplied by the aircraft industry:	
		THC, CO: Control technology is available for retrofit as well as new engine applications.	NO_x: The control techniques for NO_x are complex and uncertain. They have only been successfully demonstrated in some of the large commercial jet (T-2) class engines.
9.	Rudy (1976) p. 4, Figure 4	Air blast techniques to improve fuel atomization and fuel and air flow scheduling to increase the idle stochiometric ratio have been demonstrated in experimental combustors in the NASA Experimental Clean Combustor Program (ECCP).	
	p. 5, Figure 6	THC: Reductions over 80% were measured. CO: Reductions between 30% to 50% were measured.	NO_x: While reductions around 90% are theoretically possible in a homogeneous prevaporized-premixed flame, they have only been achieved in "fundamental" laboratory conditions.
	p. 9	THC, CO, Smoke: "Modifications to conventional combustors (improved fuel atomization and fuel-air flow distribution as shown in Figure A-4-4) can provide the capability to effectively reduce low power emissions (CO and HC) and smoke with a minimum impact on complexity and a low development risk".	NO_x: Effective control of NO_x in addition to HC and CO and smoke will require implementation of staged or variable geometry type combustor concepts. Greater hardware complexity and high to very high development risks are involved.
10.	Blazowski (1974) p. 36, 88	THC, CO: Significant emission reductions are possible using current technology. HC and CO emissions are related to engine efficiency (η_c) where η_c = 96% is currently possible for high pressure ratio engines and η_c = 92% for low pressure ratio engines. Efficiencies of 98%-99% are deemed achievable with available technology and are proposed ((eventually adopted)) as Air Force engine emission goals.	NO_x: Slight NO_x reductions (less than 25%) are possible with minor modifications. Demineralized water injection has been shown to effectively reduce NO_x but has unacceptable weight penalities.
11.	Swihart (1971) p. 95	THC: Simple designs can be used to eliminate raw fuel vented to the atmosphere. Roughly a liter of fuel per aircraft is ejected each time an engine is shut down and re-started. The common practice was to catch the fuel in a small tank and vent overboard after take-off. A simple scavage pump and return line to the fuel tank can eliminate this HC emission.	
	p. 95	THC, CO: Fuel sectoring where fuel is supplied only to every other injector may be applied to improve combustion	



(SOURCE: Pratt & Whitney Aircraft, 1970)

TYPICAL TURBOJET, TURBOPROP, AND TURBOFAN ENGINES

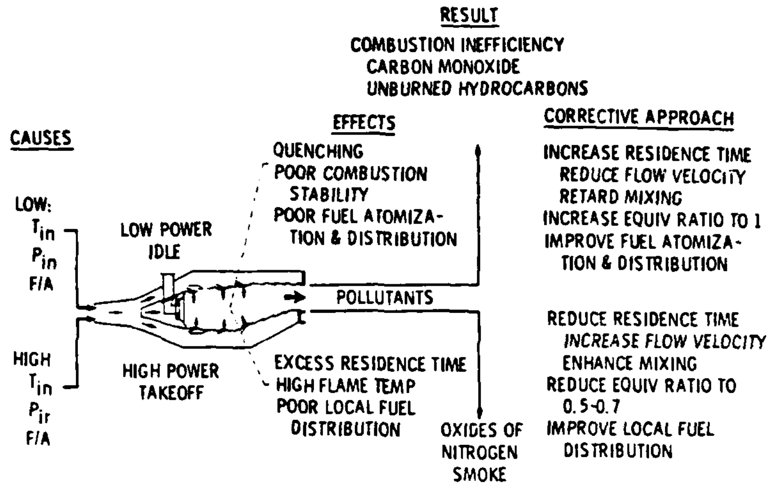
FIGURE A-4-1



(SOURCE: Pratt & Whitney Aircraft, 1970)

TYPICAL TURBOFAN ENGINE SHOWING COMBUSTION CHAMBER IN RELATIONSHIP TO ENTIRE ENGINE

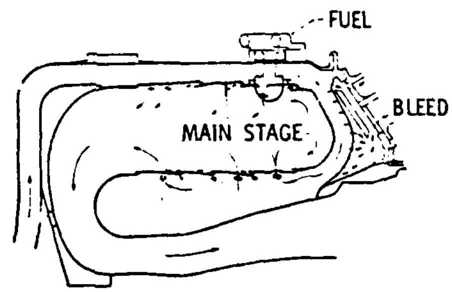
FIGURE A-4-2



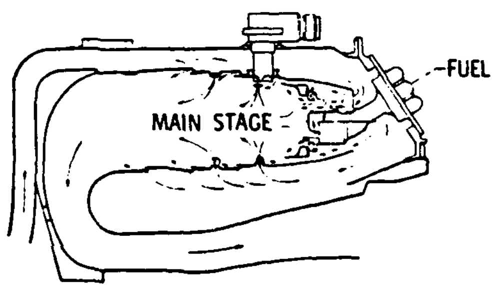
(Illustration from: Rudy, 1976)

AIRCRAFT GAS TURBINE POLLUTION CONSIDERATIONS. High and low power settings have different operating conditions which cause different pollution emissions. The dilemma of the engine designer is shown where corrective approaches for THC and CO are often the opposite from approaches for NO_x.

FIGURE A-4-3



(a) MODIFICATIONS TO BASELINE COMBUSTOR.

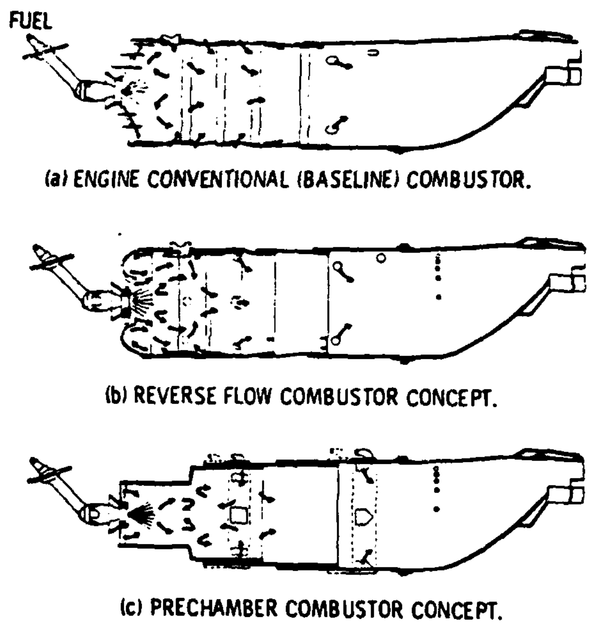


(b) PILOTED AIRBLAST INJECTION COMBUSTOR CONCEPT.

(Illustration from: Rudy, 1976)

PRIMARY ZONE ENRICHMENT, DELAYED DILUTION, AND AIRBLAST CONCEPTS FOR THC AND CO AND SMOKE CONTROL. Illustration (a) uses increased combustor bleed air to increase the equivalence ratio. Illustration (b) uses air assisted fuel injection (airblast) to increase fuel atomization and distribution. It also has variable geometry features increase residence time but are more mechanically complex to produce.

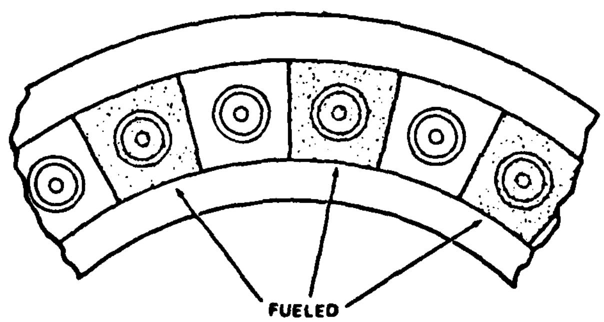
FIGURE A-4-4



(Illustration from: Rudy, 1976)

REVERSE FLOW AND PRECHAMBER CONCEPTS FOR THC AND CO CONTROL. Compared with illustration (a), illustration (b) uses the reverse flow concept to improve fuel distribution along the combustor liner wall. Illustration (c) depicts a smaller primary zone prechamber which increases local equivalence ratios by delaying dilution.

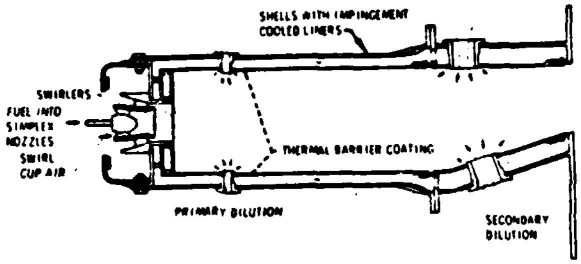
FIGURE A-4-5



(Illustration from: Swihart, 1971)

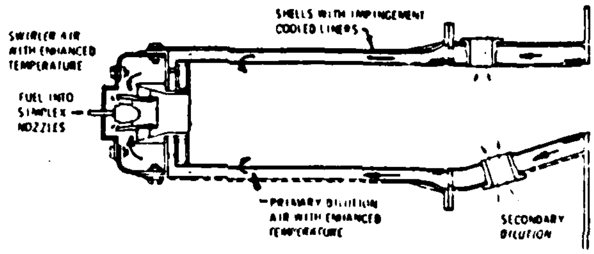
FUEL SECTORING CONCEPT FOR THC AND CO CONTROL.
An annular combustor with numerous fuel injectors is shown. During idle and low speed engine operation, only every other fuel injector is used to increase local equivalence ratios and therefore combustion temperatures.

FIGURE A-4-6



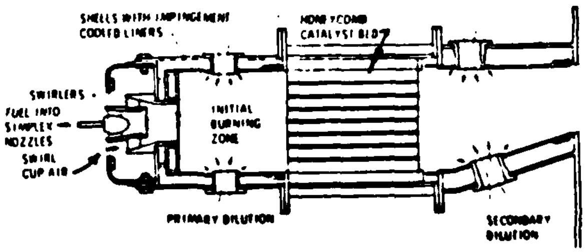
THERMAL BARRIER CONCEPT FOR THC AND CO CONTROL.
A coating on the inside of the combustor liner allows higher gas temperatures near the liner to minimize wall quenching of the combustor kinetics.

FIGURE A-4-7



RECUPERATIVE COOLING CONCEPT FOR THC AND CO CONTROL.
All primary combustion air is first preheated to increase combustion reaction rates. Air swirlers also aid in fuel atomization.

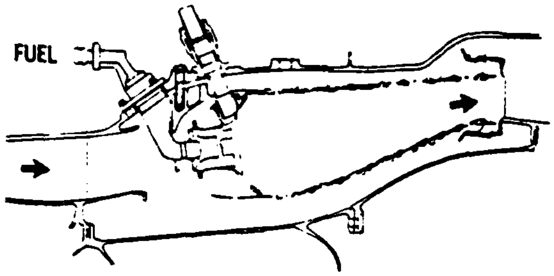
FIGURE A-4-8



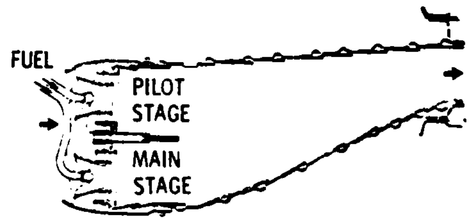
CATALYTIC CONVERTER CONCEPT FOR THC, CO (AND POTENTIALLY NO_x) CONTROL. A low equivalence ratio (0.30 at idle) in the primary zone lowers overall temperature to protect the catalytic bed and lower NO_x formation. The ceramic honeycomb catalyst bed consumes unburned THC and CO products. This concept is quite advanced.

(SOURCE: Mularz, Gleason, & Dodds, 1979)

FIGURE A-4-9



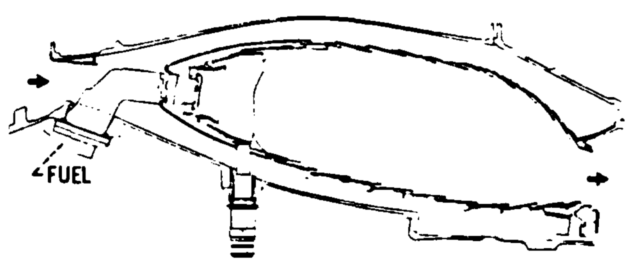
(a) ENGINE CONVENTIONAL (BASELINE) COMBUSTOR.



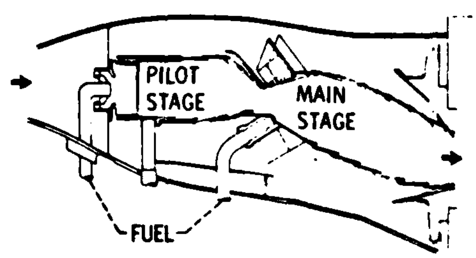
(b) DOUBLE ANNULAR CONCEPT. (SOURCE: Rudy, 1976)

DOUBLE ANNULAR STAGED COMBUSTOR CONCEPT FOR NO_x AS WELL AS THC AND CO CONTROL. The pilot stage is optimized for THC and CO control during idle. The main stage is only used at high power and is designed to limit NO_x emissions.

FIGURE A-4-10



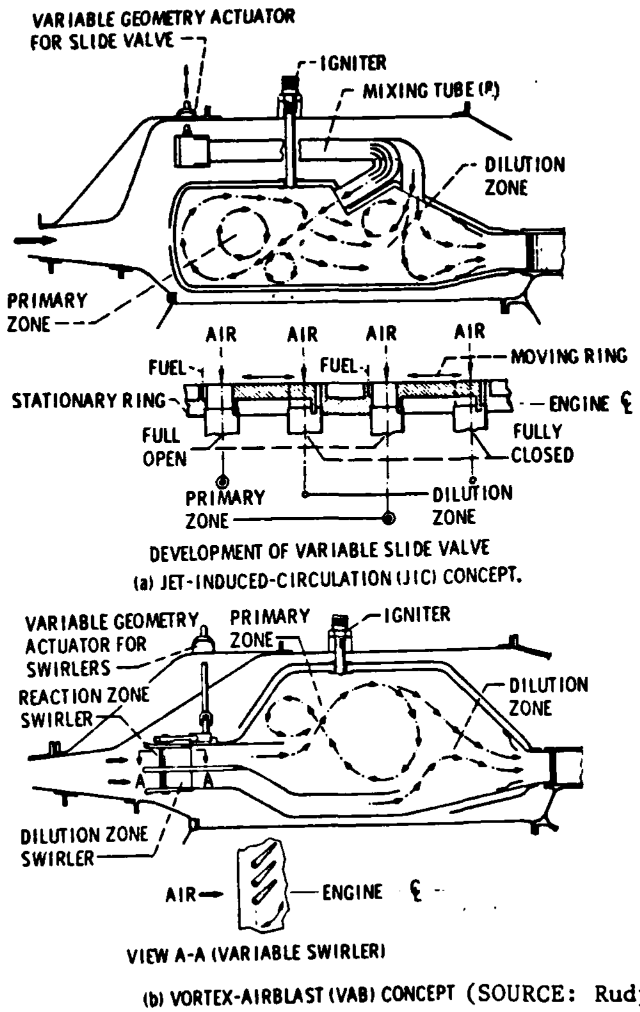
(c) ENGINE CONVENTIONAL (BASELINE) COMBUSTOR.



(d) Axial Staged Concept (SOURCE: Rudy, 1976)

AXIAL STAGED COMBUSTOR CONCEPT FOR NO_x AS WELL AS THC AND CO CONTROL. High intensity swirlers downstream of the main stage cause intensive mixing for THC and CO control plus flame stability under lean mixture combustion for NO_x control. Concepts of fuel scheduling, lean mixture combustion, premixing, and quick quenching can be combined.

FIGURE A-4-11



(SOURCE: Rudy, 1976)

VARIABLE GEOMETRY COMBUSTOR CONCEPT FOR NO_x AS WELL AS THC AND CO CONTROL. Both (a) and (b) designs allow for independent control of fuel flow and air flow distribution. This theoretically allows more precise control of combustion parameters for low emissions but is mechanically complex, and has not been successfully demonstrated. Illustration (a) shows a variable slide valve for primary and dilution zone flow control. Illustration (b) shows adjustable swirler vanes to alter the effective primary and secondary zones.

FIGURE A-4-12

APPENDIX SECTION A.5

TEST OF HYPOTHESIS H-5

Hypothesis H-5: "Aircraft engine emission controls, as required by emission standards, significantly improve air quality".

Issues: Without reasonable evidence that air quality benefits will result from aircraft emission controls, there is little incentive to implement expensive control standards. In effect, why seek a solution if a problem does not exist?

Discussion: This test of hypothesis first requires further definition to "significantly improve air quality". The aviation industry has long maintained that aircraft engine control standards would produce insignificant air quality benefits. The argument is that aircraft engine emission standards are unjustified unless they reduce or prevent adverse health or welfare effects (The NAAQS are taken as measures of health and welfare effects -- see H-1). This viewpoint is most appropriate for CO levels from aircraft. Since the reactivity of CO is very low, the maximum impact from aircraft related CO is expected to be near the airport emission sources. Extensive ambient air quality studies, based on ambient measurements and dispersion modelling, should adequately be able to define a CO problem if there is one.

Similar arguments are not appropriate for THC and NO_x, however. An important conclusion from the 1978 Reston Conference on Air Quality and Aviation is that THC and NO_x emissions from aircraft should be considered on a regional basis (Sundararaman, 1979). Both pollutants are reactive in the atmosphere. Potential air pollution problems, if any, are expected somewhat downwind of the airport boundaries. Roughly 94% of the

NO_x emitted from aircraft is in the form of NO which is of little health concern. Conversion to NO_2 must take place before health related standards are applicable.

Aircraft THC emissions are not of direct health concern but only if they are contributors to high levels of photochemical oxidants (O_x) produced in the atmosphere. Since many NO_x and THC emission sources are responsible for high O_x levels, aircraft must be considered along with these other sources and not as an isolated problem.

Findings: A test of this hypothesis must be done somewhat differently for CO which has a localized air quality effect than for THC and NO_x which has more of a regional effect. For CO, the studies from Table A-3 as used for Hypothesis H-3 are also appropriate to evaluate this hypothesis. The same ordinal ranking scale applies. Results are repeated below (the "true" and "false" columns are reversed due to hypothesis wording differences):

	True (Aircraft Controls Significantly Improve Air Quality)	Marginal	False
CO:	8,11	12,15,19,25,27	1,2,4,5,6,7,9,13, 14,16,17,18,19,20, 21,22,23,24,26,28, 29,30,31

Analysis of the CO evidence clearly indicates a "false" hypothesis outcome. Both the largest number of studies and the most significant studies (indicated by low ordinal rankings) are in the false column above. References 8 and 11 appear to be "true" because of inaccurate conclusions from the limited measurement data available at the time of the reports (Yamartino, 1980).

Few studies were found which deal with THC and NO_x emissions from airports as a regional problem (Table A-5). Most ambient monitoring studies were therefore not relevant for this hypothesis. A simple ranking scheme is used. The only two photochemical studies which involve airports and aircraft are given the highest rankings, 1 and 2. The remaining 4 reports are ranked in reverse chronological order. Results from this work are also summarized and given an unranked "0" order.

A summary of the reference rank orders are as follows:

	True (Aircraft controls significantly improve air quality)	False
THC(O_x):	0,2,3,5,6	1
NO_x:	0,2,3,5,6	1,4

The limited evidence supports a conclusion that aircraft and airport THC and NO_x emissions have an effect on air quality. Aircraft controls, shown in H-4 to cause over a 70% THC reduction and up to a 40% NO_x reduction, are therefore expected to cause some air quality benefits. The strength of the evidence is questionable, however. Considerable technical uncertainities are associated with all of the studies shown.

The elaborate model application in Study 1 does not suggest airports cause significant increases in O_x levels. Study 2 concludes aircraft can cause significant O_3 increases but is based on outdated chemical mechanisms and aircraft emissions. Logical arguments in this work suggest that THC emissions and potential emission reductions from aircraft are significant when compared to stationary sources considered candidates for New Source Performance Standards (NSPS). The remaining THC and NO_x studies on Table A-5 are placed in the "true" category but have various weaknesses as described under each source.

Conclusions: Air quality problems due to CO from aircraft related emissions are not expected on or near the airport boundaries. The vast majority of published airport air quality studies show that levels are well below those of health related standards. The conclusion is therefore made that regulat' .s to control CO emissions from aircraft will not significantly improve the air quality since no problems in these airport areas are knows to exist.

The effects of THC and NO_x aircraft controls are much more difficult to assess since potential problems would not occur until after atmospheric reactions cause the formation of O_x and NO_2. The complexity of the atmospheric photochemical process causes this assessment difficulty. In the absence of evidence to the contrary, the null hypothesis that THC and NO_x controls improve air quality is accepted.

TABLE A-5

TEST OF HYPOTHESIS H-5

AIRCRAFT ENGINE EMISSION CONTROLS SIGNIFICANTLY IMPROVE AIR QUALITY

REF. 1&2 STRONGEST, OTHERS IN REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
0*	This Work	NMHC(O_x), NO_x: Comparison of annual aircraft emissions with the 40-60 stationary sources which EPA is considering for NSPS reveals that aircraft are the 10th or 11th highest source (further discussion is in Chapter VIII).	
1.	Duewer (1978) p. 91		NMHC(O_x), NO_x: A photochemical Eularian grid model is applied to the San Francisco Bay area and three civil airports. Results suggest airport emissions may cause increases in peak O_3 levels of up to 0.003ppm. ((Although San Francisco is a non-attainment area for O_3, airport emissions do not appear to be significant contributors to the 0.12ppm NAAQS)). Also, aircraft NO_x increases by 1985 could slightly decrease peak O_3 levels within much of the area modelled. Results from this complex model are tentative since they are very sensitive to assumed THC/NO_x ratios of emissions and ambient background.
2.	Whitten (1976) p. 98	THC(O_x), NO_x: Computer simulations with chemical kinetic mechanisms suggest blending automotive and aircraft emissions may result in increased ozone production. Improvements in aircraft emissions could reduce ozone formation by (1) lowering the overall emissions and by, (2) shifting the THC/NO_x ratio. Control strategies are most effective when they shift away from the intermediate THC/NO_x ratios associated with high ozone production. A reduction in aircraft emissions with a high THC/NO_x ratio when mixed with automobile emissions with a low THC/NO_x ratio would cause a shift to a lower blended ratio. ((The chemical mechanisms and THC/NO_x ratios from aircraft used in this study are so badly dated that all findings are highly questionable)).	
3a.	Yamartino, Smith, et.al. (1980) p. 20	THC: After a review of most reports on the impact of aircraft emissions on air quality, the conc lusion is made that aircraft contribute to ozone air quality problems in many urban areas. Control of many sources the size of airports is needed to achieve the ozone NAAQS. ((Convincing arguments which relate aircraft emissions to other "small" sources are not given)).	

Footnote:
*Evidence from this work is not ranked with other sources but is considered in the conclusions of this hypothesis.
**Comments by this author or conclusions not part of the reference cited are indicated by ((.....)).

TABLE A-5 (CONT'D.)
TEST OF HYPOTHESIS H-5

AIRCRAFT ENGINE EMISSION CONTROLS SIGNIFICANTLY IMPROVE AIR QUALITY

REF 1&2 STRONGEST, OTHERS IN REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
	p. 69	Hourly NO_2: Both extrapolation of cumulative frequency distributions of measured airport data to the 99.99% probability level as well as dispersion modelling indicate the possibility of airport concentrations in the 0.2 to 0.5ppm range. ((This evidence is suggestive of a potential problem but weak for two reasons: (1) There are considerable uncertainties in the NO_x projections above 0.2ppm due to: (a) Unknown $NO \rightarrow NO_2$ conversion rates where the worst case NO_x was used in dispersion models. (b) Inherent difficulties in basing conclusions with nationwide implications on extrapolations of measured data at one airport to the 99.99% probability level. (2) Even if aircraft related levels reach 0.2ppm, there is no current NO_2 short term standard. There is significant controversy over whether existing health effects data can support a short term NO_x standard)).	
3b.	Segal (1981) p. 2		CO: Extensive analysis of recent measured and modelled data indicate the "worst case" concentrations due to aircraft at the busiest airports are 2-7ppm. The air quality impact is therefore considered quite small.
4.	Jordan (1979) p. 123		NO_2: Based on past monitoring and measurement studies and unless emission levels are increased substantially, violations of the World Health Organization standards (.10-.12ppm hrly. average not to be exceeded more than once per month) would be very unlikely. From modelling, maximum hrly. NO_x from an airport is 30%-50% of a 100 megawatt power plant meeting the New Source Performance Standards. ((Uncertainty in future aircraft emission levels and the lack of a short term NO_2 NAAQS make this evidence tentative)).
5.	Cirillo (1975) p. 98	THC(O_x): Airport sources are equivalent to the Atlanta central business district in emission density and air quality impact near the airport (within 14 km). ((While the airport HC emissions appear significant, the O_x potential is undefined)).	
	p. 105 p. 110	NO_2: The worst case hrly. levels from the airport are .25ppm at 6 km. The summer hrly. average is predicted as 0.03ppm at 6 km. ((Complete and instantaneous $NO \rightarrow NO_2$ conversion is assumed)).	
6.	EPA (1972) p. 35 p. 49	This EPA Support Document was issued along with the proposed aircraft standards. Conclusions were: NMHC(O_x), NO_2: Airports quite likely exert a localized impact on air quality in excess of NAAQS levels. This is based on emission densities, monitoring and modelling where NMHC was well above the 0.24ppm Guideline and NO_2 levels are comparable to NAAQS levels. ((The 0.24ppm NMHC Guideline for O_x control is a crude indicator and no longer recommended. As stated in Yarmartino (1980, p. 33), the NO_2 levels predicted by this dispersion model application appear to be grossly over-predicted due to the instantaneous $NO \rightarrow NO_2$ assumption)).	

APPENDIX SECTION A.6

TEST OF HYPOTHESIS H-6

Hypothesis H-6: "Aviation emission controls are best implemented as uniform national standards".

Issues: Since air quality problems from aviation are believed to occur at only some large commercial airports, if at all, stringent control of all aircraft engines may be less desirable than more lenient controls in combination with aircraft or airport operational changes.

Discussion: The effects of air pollution from airports are functions of the aircraft engines, airport design and location, aircraft activity levels, aircraft fleet mixture, operating procedures, and emissions by other sources such as motor vehicles. Stringent emission controls have been applied only to aircraft engines with uniform national applicability. Mandatory changes to the ground operating procedures of aircraft were proposed by EPA in 1972 (Federal Register, 1972) but never implemented. Such strategies do not have to be on a uniform national basis but can be implemented in only the local areas where beneficial. These "local control" techniques can be used to supplement, replace, or to allow less stringent aircraft engine controls.

Data Evaluation: Little technical data was found which deals with the merits of uniform national controls versus local aviation emission controls. Most studies focus on particular control strategies or make general policy statements with minimal justification given. One rigorous study was found and is given a rank order of 1 in Table A-6. All other references provide less evidence and are simply listed in reverse chronological order.

Findings: A summary of findings from the references in Table A-6 are presented below. Findings which apply to aviation pollution without clear applicability to various species are listed under a separate category. References 5 and 9 have elements which can support "true" and "false" outcomes.

	True (Arguments for only National Standards)	False (Arguments for a combination of National and Local Controls)
THC:		1,2,4
CO:		1,2,4,6
NO_x:	1,2	
Smoke:	6	
"Unspecified Aviation Pollution":	5,7,8,9	3,5,9

Data in References 1, 2, 4, and 6 indicate that techniques (such as aircraft towing or reduced engine operation) which do not have to be implemented on a uniform national basis are as effective in reducing aviation emissions as are the aircraft engine emission standards. A "false" hypothesis outcome is therefore indicated for THC and CO. While questions concerning flight safety have not been resolved, neither is there convincing evidence that such techniques are in fact unsafe. Further discussion of this issue is presented in Hypothesis H-11.

No locally controllable techniques which effectively reduce NO_x and smoke were found. Neither pollutants are serious in the low-power engine modes so that modifications to ground operating procedures have little effect. Aircraft engine controls through national emission standards appear to be the only option if reductions are desired.

Policy decisions as discussed in References 5, 7, 8, and 9 favor only Federal controls, apparently to avoid potential disruptions in aircraft travel. The Clean Air Act Amendments of 1975 specifically prohibits state or local aircraft or engine standards if different than the Federal standards. The extent to which local controls can be used to modify aircraft ground operating procedures is unclear. The FAA would have to be convinced that any such controls do not jeopardize aircraft safety.

Conclusions: Aviation emission controls are not necessarily best implemented by uniform national controls for THC and CO emissions. Localized techniques should be considered to either allow more relaxed, cost effective national aircraft engine emission standards or to further reduce THC and CO emissions at airports where serious pollution problems are evident.

Desired aircraft controls for NO_x and smoke are best implemented by engine emission standards on a uniform national (or international) basis.

TABLE A-6

TEST OF HYPOTHESIS H-6

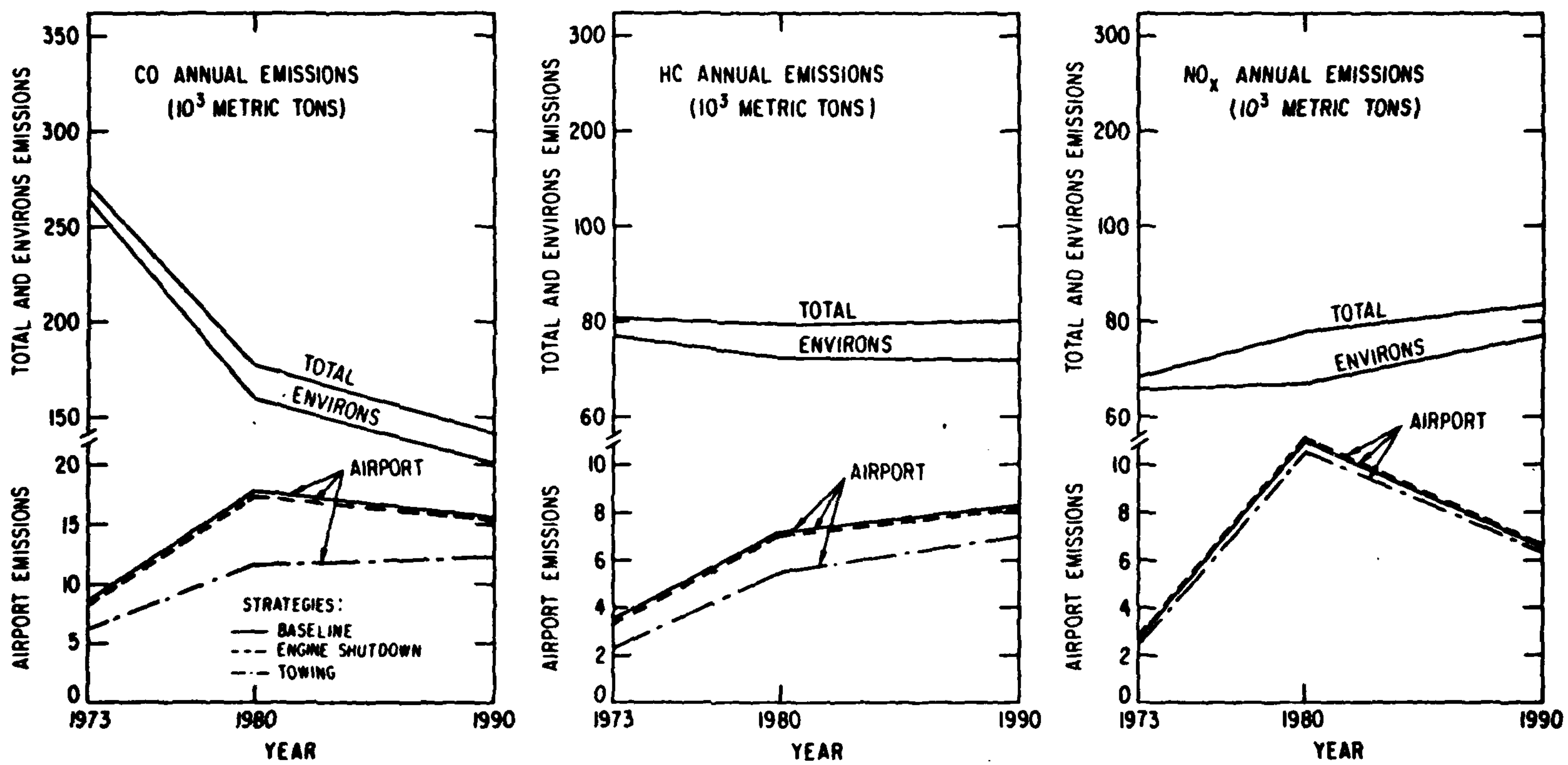
AVIATION EMISSION CONTROLS ARE BEST IMPLEMENTED AS UNIFORM NATIONAL STANDARDS

REF. 1 STRONGEST, OTHERS IN REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
1.	Cirillo (1975) pp. 32-46	This work is the only in-depth, technical study which compares strategies which could be implemented on a local basis with aircraft engine controls which must be implemented on a national basis. Emission and dispersion model techniques are applied using Atlanta Airport (Hartsfield) data. Five strategies are studied: (1) Engine shutdown during taxi where fewer engines are operated at more efficient thrust settings. (2) Aircraft towing by a specially designed tractor between the runway and the passenger terminal. (3) Capacity control where aircraft activity is reduced by increasing passenger load factors. (4) Fleet mix control where wide body aircraft would replace 25% of the smaller aircraft. (5) Aircraft engine emission standards as issued in 1973.	
	p. 47	Note that aircraft are responsible for 69% of the THC, 58% of the CO, and 78% of the NO_x at the Atlanta airport. Airport vehicular source controls and land-use controls were not studied. Airport design and other land-use controls which minimize noise impacts will also improve concentrated air pollution densities.	
	p. 162	NO_x: Control of aircraft engine emissions is the only strategy to achieve NO_x reductions. ((See Figure A-6-1 where towing and engine shutdown cause little change from the airport NO_x emissions. Assumed compliance with national emission standards set in 1973 accounts for the 1980 to 1990 emissions decrease)).	THC, CO: Aircraft towing, engine emission standards, and fleet mix control provide significant emission reductions. ((See Figure A-6-1 for the effect of aircraft towing projected through 1990. Dispersion model results for all 5 strategies are shown in Figure A-6-2 and A-6-3. Aircraft towing is more effective in reducing air quality concentrations than engine emission controls)).
2.	Gelinas (1979) p. 125	This study, funded by the California Air Resources Board, studied ways to reduce air pollutant emissions at airports by controlling aircraft ground operations. Strategies included: (1) Aircraft towing, (2) Engine shutdown — Described in Reference 1 in this table (3) Control the time of aircraft departure. (4) Assign runways to minimize taxi times.	
		NO_x: All strategies were ineffective (less than 5% reduction).	THC, CO: Effective reductions (25%-50%) are predicted with the towing and engine shutdown strategies.
3.	Mellor (1973) p. 5 (Lawson)	This work summarizes a North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development (AGARD) conference with over 50 individual studies.	
			- Aircraft account for only about one-half of the airport pollution with the rest due primarily to ground vehicles. Thus airport planners, and others in addition to aircraft manufacturers must cooperate to minimize emissions.
	p. 6 (Round Table Discussion)		- The Europeans, especially British and Germans, questioned the specific form of the EPA standards but not the overall objective of such standards to minimize environmental pollution. Emphasis could be given to locations with severe pollution with less of a burden on airports without problems.

TABLE A-6 (CONT'D.)
TEST OF HYPOTHESIS H-6

AVIATION EMISSION CONTROLS ARE BEST IMPLEMENTED AS UNIFORM NATIONAL STANDARDS

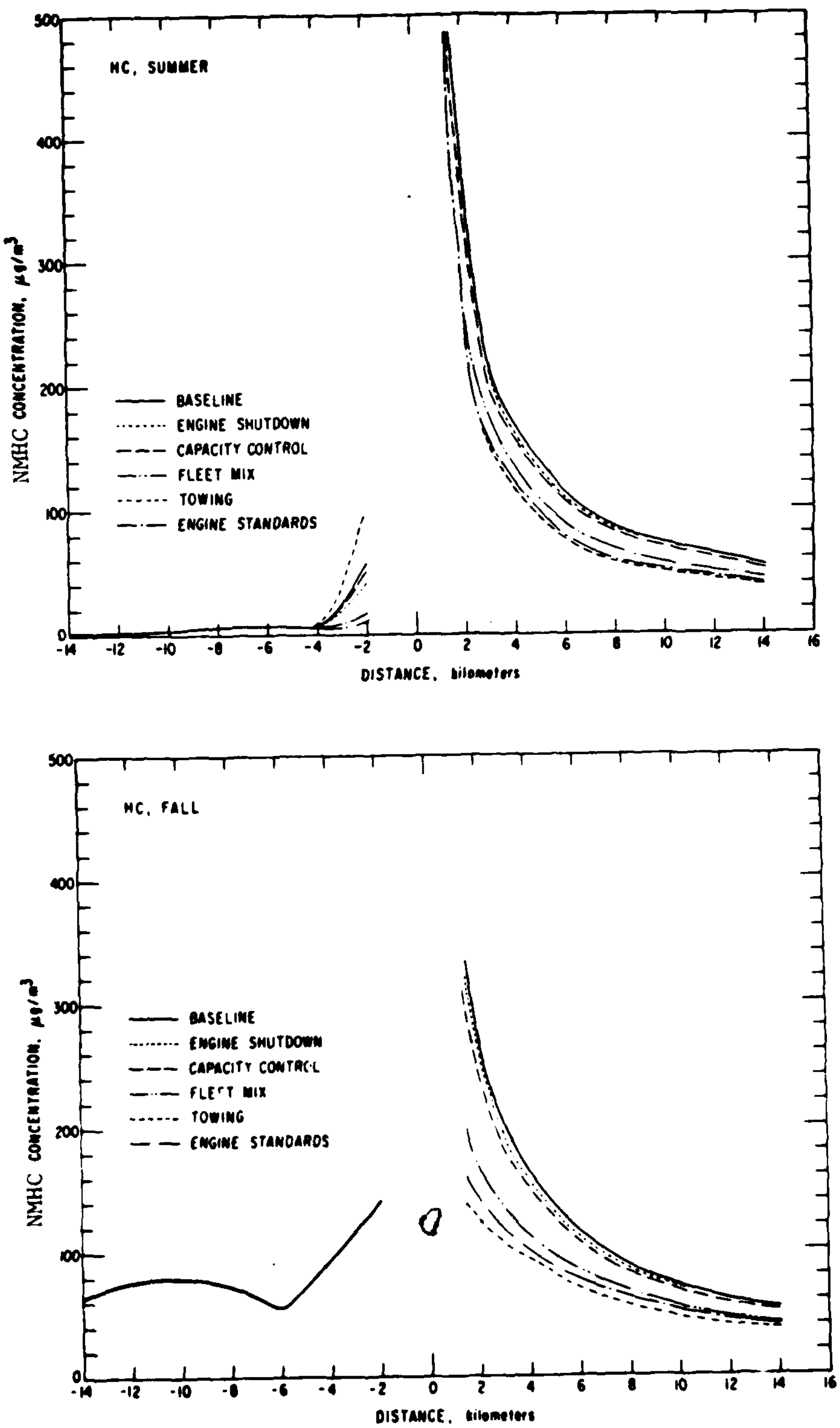
REF. 1 STRONGEST, OTHERS IN REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
4.	Federal Register (1972)		THC, CO: EPA estimated that 50%-70% of the aircraft emissions at major carrier airports could be eliminated by modification of ground operating procedures. The intention of proposing mandatory procedures was expressed. Specific procedures were not proposed due to safety questions raised by the Department of Transportation (DOT). The regulatory justification is that 29 of the 33 largest airports were in Priority I Regions for control of THC and CO.
5.	EPA (1972)	This support document to the EPA Notice of Proposed Rule-Making for Aircraft Engine Controls and Ground Operation of Aircraft concluded that:	
	p. 79	Overall Aircraft Emission Control: Incorporation of emission controls into new engine designs is the most cost-effective method overall (including NO_x).	THC, CO: Ground operation procedure modifications are cost-effective for reducing these pollutants.
6.	George, et al. (1972) p. 508 p. 515	Smoke: The Federal Clean Air Act, signed into law on December 31, 1970, pre-empted a California law limiting visible emissions from aircraft which would have been effective the very next day. ((Smokeless combustors have since been installed on nearly all commercial aircraft and all recent vintage military aircraft)).	CO: Both ambient measurements and emission inventories have indicated that auto traffic is a significant contributor to airport pollution levels. ((This implies the usefulness of land-use planning)).
7.	"The Clean Air Act" (1970) Section 233	The December 31, 1970 Clean Air Act Amendments added the following: "No state or political subdivision thereof may adopt or attempt to enforce any standard respecting emissions of any air pollutant from any aircraft or engine thereof unless such standard is identical to a standard applicable to such aircraft under this part".	
8.	U.S. Senate (1970) p. 3	Testimony by the Department of Health, Education, and Welfare (HEW) before the U.S. Senate Subcommittee on Air and Water Pollution included: "It is the Department's conclusion that adoption and enforcement of state or local emission control regulations pertaining to aircraft cannot be adequately justified at this time. The Department recommends that if and when regulations become necessary, the rationale used to develop Federal rather than local emission standards for motor vehicles be applied to aircraft". ((This comment is an apparent response to lawsuits in which New Jersey, Illinois, Michigan and California sought to regulate aircraft pollution)).	
9.	HEW (1968) p. 5	This HEW report to the U.S. Congress, as required by the Air Quality Act of 1967, indicates:	
		State or local emission controls are not justified at this time due to the small air pollution contribution by aircraft and due to the practical problems from state or local actions.	Nevertheless, HEW recognizes that these state and local agencies, in cooperation with FAA, can best limit pollution exposures with careful airport site selection, airport design, and conduct of ground operations.



(SOURCE: Cirillo, <u>et.al.</u>, 1975)

EFFECT OF AIRCRAFT TOWING AND SHUTDOWN STRATEGIES AT ATLANTA AIRPORT

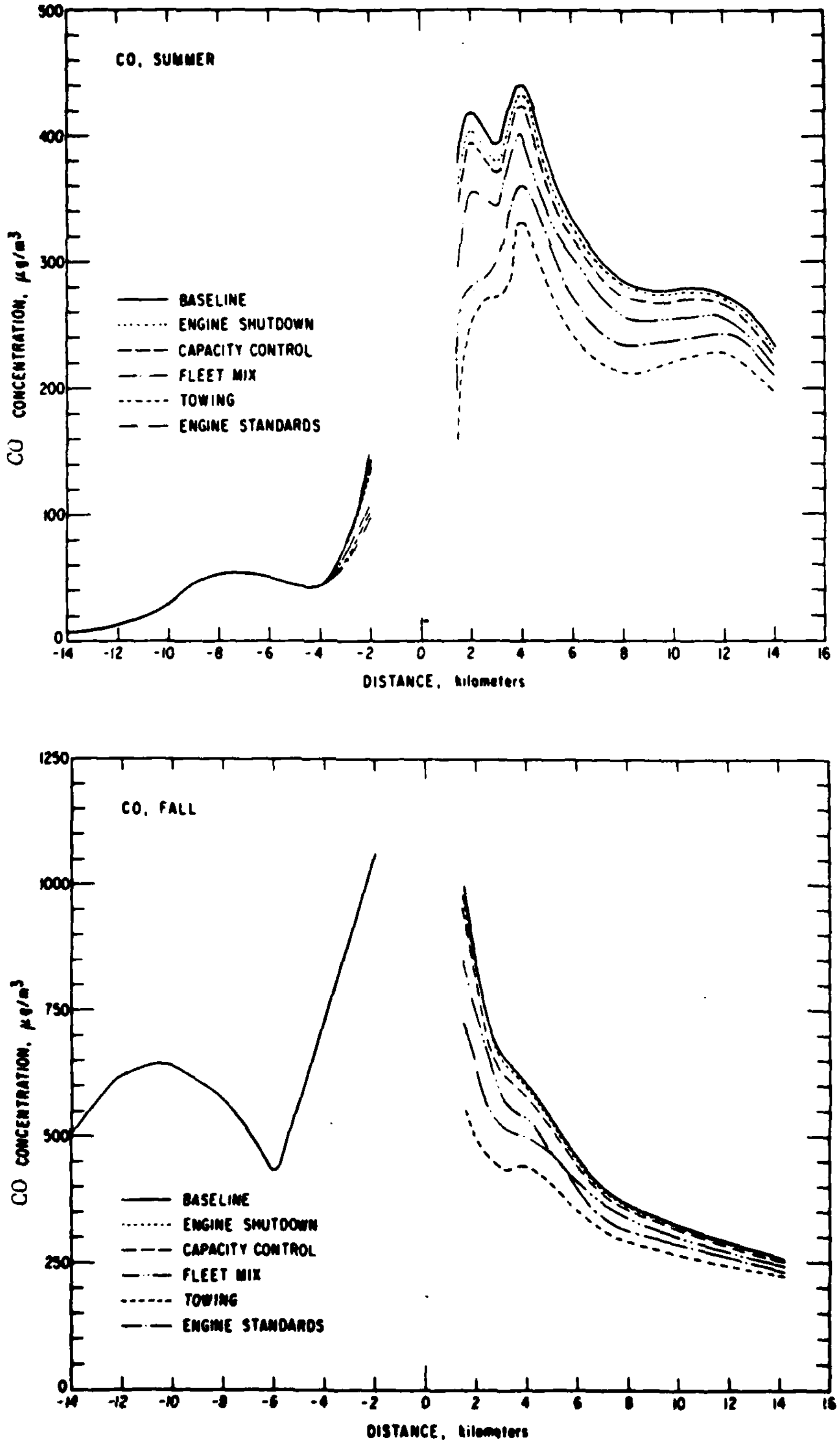
FIGURE A-6-1



(SOURCE: Cirillo, 1975)

EFFECT OF AVIATION CONTROL STRATEGIES ON PREDICTED NMHC CONCENTRATIONS AT ATLANTA AIRPORT

FIGURE A-6-2



(SOURCE: Cirillo, 1975)

EFFECT OF AVIATION CONTROL STRATEGIES ON PREDICTED
CO CONCENTRATIONS AT ATLANTA AIRPORT

FIGURE A-6-3

APPENDIX SECTION A.7

TEST OF HYPOTHESIS H-7

Hypothesis H-7: "Current national aircraft engine emission standards are too stringent".

Issues: Relaxation of the EPA regulated limits and compliance deadlines has been petitioned by the aircraft engine companies because of technological difficulties. Revised standards were proposed by EPA on March 24, 1978. Final rule-making is still pending. The issues are whether the original EPA national emission standards are too stringent and whether the 1978 proposed standards are too stringent.

Discussion: The meaning of "too stringent" must be clarified before a test of the above hypothesis can be attempted. Whether any standard is too stringent depends on several policy questions upon which technological evaluations are based. The first policy question addressed here is if the standard should be based on ambient air quality or control technology considerations. The preamble of the original EPA standards 38FR19088, July 17, 1973, stated:

> "The standards proposed herein are not quantitatively derived from air quality considerations discussed in the study report cited above ("Aircraft Emissions... 1972") but, instead, reflect EPA's best judgement as to what reduced emission levels are or will be practicable to achieve for turbine and piston engines".

A somewhat different discription is found in the preamble to the latest proposed standards, 43FR12615, March 24, 1978, page 1889, and states that:

> "In determining appropriate levels for standards (for commercial aircraft), consideration was given to air quality needs, technical feasibility, and comparative cost effectiveness".

Exactly how these three factors were considered in the proposed regulatory levels is unclear. Discussion in the same preamble suggests the basic determination of the quantitative control limits in the emission standards still appears to be made from judgements of the best practicable controls. This technological basis for the stringency of the standard will be assumed for the testing of this hypothesis. Alternative techniques for setting control limits are explored in Chapter VIII.

The second policy question is how to define what technological levels are to be considered as "practicable" for the control of emissions. Control limits can be established at levels which are currently available in production aircraft engines with the lowest emissions, demonstrated in prototype engine combustors so that little, if any, further development is needed, or judged achievable in advanced concepts while allowing further development time to obtain compliance. All such concepts have been used by EPA according to the perceived urgency to control an individual source category. The current policy toward aircraft engine emission standards is not completely clear and could easily change in the future. Therefore the assumption made in this hypothesis is that the best technology which has been demonstrated will be evaluated against the stringency of the standards proposed for 1981 implementation. The application of advanced technology will be evaluated against the stringency of the standards proposed for 1984 implementation.

Data Evaluation: Studies which compare the maximum practicable control technology with the national aircraft engine emission standards are presented in Table A-7. Two categories are used. Data and conclusions which deal with the original 1973 standards with modifications prior to 1978 are listed in the first category. Data which relate to the

1978 proposed standards are in the second category. References are listed in an arbitrary order since a more elaborate approach appears to be of little benefit. Data tables which support conclusions in Table A-7 are reproduced in Tables A-7-1 through A-7-8 and Figures A-7-1 through A-7-8.

Independent sources of data to evaluate this hypothesis are quite limited. Evaluations by the EPA technical staff are published in the Federal Register and supporting documents. Results of the NASA sponsored research provide valuable quantitative comparisons but are based on experimental studies, usually with advanced technology concepts. These results cannot be directly translated to what is practicable in operational aircraft engines. The limited data published by aviation related companies and organizations are also included in Table A-7. They sometimes are based on logical arguments but with minimal supporting data.

Findings: A summary of studies used to evaluate Hypothesis H-7 is shown below. The study numbers are not weighed according to the strength of the evidence. Also, the "true" and "false" outcome is highly dependent on the two policy assumptions in the "Discussion" paragraph above.

I. Pre-1978 Standards	True (Levels in Standards too Stringent)	False (Keep Levels of Control with Minor Relaxation of Deadlines)
THC:		1,2(T4,APU,P2),3,5,6,7(P2)*
CO:	2,5,9(T2,T4)*	1,2(T4,APU,P2),3,6,7(P2)
NO_x:	1,2,3,4,5,9(T2,T4)*	2(P2),3(P2),7(P2)*
Smoke:	8(T3)*	4,7(P2)*

*Results apply only to indicated class of engine

II. 1978 Recommended Standards	True (Levels in Standards too Stringent)	False (Keep Levels of Control with Minor Relaxation of Deadlines)
THC:	11(1984 Std.)	9(T2,T4,P2)*,11(1981 Std.), 12,13
CO:	9(T2,T4)*,11,13,14	9(P2),12
NO_x:	9(T2,T4)*,10(low quality fuels),11, 12,13,14	9(P2)
Smoke:	10(low quality fuels)	9(T2,T4,P2)*,11,13

*Results apply only to indicated class of engine.

The vast majority of the evidence considered indicates that the levels of control regulated for THC emissions are reasonable. The technology is well developed for effective reductions in the order of 80%-90% of current production engines. Relatively minor engineering changes, primarily affecting the fuel atomization and fuel and airflow distribution, can be implemented within several years for new and in-use engines. Reference 11 in Table A-7 does claim that the 50% reduction proposed for 1984 and in addition to the 80%-90% previously required is too stringent, at least for certain engines.

The evidence of whether CO standards can be met is mixed. Conclusions depend largely on the class of engines considered and the stringency of NO_x standard which must be simultaneously met. Engines in the P2, and APU classes can meet the control limits. Regulations for the APU class have been eliminated, however, on the judgement that the minimal air quality benefits did not justify the costs of control. Although the control technology is fairly well developed, engines in the T2 class and those of an old design have the most difficulty in successful implementation of this technology (Sources 2,5, and 9). Stringent controls proposed for 1984 which include NO_x make CO reductions more difficult since design parameters which reduce one pollutant tend to increase the other pollutant (see Hypothesis H-4).

The evidence concerned with NO_x control supports the "true" hypothesis with the exception of the P2 engine class for which the standards provide a "ceiling" on future emissions rather than reduce current levels. Concepts which effectively reduce NO_x emissions are still in the early stages of development. NASA-supported research efforts have had mixed success. Reductions have been obtained with experimental combustors but often at the expense of increasing smoke to the visibility range or of not achieving CO goals. Just as importantly, the increased mechanical complexity and weight required with these advanced concepts, are of concern from the safety and durability viewpoints. Major development test and evaluation programs are needed to demonstrate the levels of control proposed for 1984 standards. Also, as described in Reference 10 in Table A-7, alternate fuel sources with fuel bound nitrogen can easily nullify progress made toward emission reductions.

The standards for control of smoke are generally achievable. Little evidence to the contrary is noted in Table A-7. The older JT3D engine in the T3 class has a specific waiver to postpone compliance until 1985 when noise rules will cause engine replacements to be made (Reference 8). Future alternate fuels could complicate compliance for all engines. With these two exceptions, however, the control levels for smoke seem practicable.

Conclusions: The regulated limits for hydrocarbon and smoke from aircraft engines are not deemed too stringent. The control technology has been demonstrated on production engines or to the point where only minor, low risk development programs are required for compliance.

Levels of CO proposed for 1981 implementation have not been demonstrated on many types of engines. Additional testing of control concepts such as fuel staging is needed to insure practicability. More stringent controls proposed for 1984 implementation are even more doubtful when combined with simultaneous NO_x controls.

Emission standards to reduce NO_x can only be met by implementation of advanced technology concepts. Such concepts have shown promise in experimental studies but require high risk development programs of the complex hardware to meet all design criteria for safety, durability, and low emissions.

TABLE A-7
TEST OF HYPOTHESIS H-7

CURRENT A/C ENGINE EMISSION STANDARDS ARE TOO STRINGENT

ARBITRARY ORDER	SELECTED REFERENCE	TRUE	FALSE
I. Hypothesis as related to the EPA Emission Standards prior to the 1978 proposed ammendments.			
1.	Federal Register (1978) p. 1887, Column 3 p. 1889, Column 2 p. 1890, Column 1	NO_x: EPA concludes: "...The full degree of NO_x control called for in the existing standards is not technically achievable in the foreseeable future". NASA sponsored research did not achieve levels low enough to comply with existing standards and a relaxation of newly manufactured levels of 30% is necessary. Control of NO_x for all commercial engines over 6,000 lbs. thrust is proposed. NO_x control technology will take an additional 3 years to implement.	HC, CO: EPA considers the newly manufactured engine (NME) standards technically feasible for T2 class engines over 100 kilo Newtons. The EPA position at this time was that some difficulty has been experienced, but except for engines with less than 27 kilo Newtons thrust implementation of the current standards need not be delayed beyond a 2 year extension.
2.	EPA (1978)	The EPA technical staff takes the following position regarding the manufacturers' claim that current standards are too stringent in level of control and compliance date:	
	p. A-3 p. A-5 p. A-6	CO: The technology to meet standards by 1979 can be met by only a few engines. Problems are with CO in the T2 class with the CF6-6, CFM56, RB211-22B and all older engines. NO_x: Standards can only be met 3-4 years after the 1979 compliance date.	HC, CO (T4 Class Engine): The JT-8D family of engines achieve these standards. HC, CO (APU's): The control technology is now available. HC, CO, NO (P-2 Class Engines): The control technology is now available.
3.	Munt (1976)	An EPA staff assessment of control technology as supplied to EPA by the aircraft manufacturers prior to December 1, 1976 is shown in Table A-7-1. Report conclusions are:	
	p. v. p. iii	NO_x: The future availability of control is quite uncertain. The requisite technology has been demonstrated in some experiments but only in a few engines. Effective control may be generally available in classes T1 and T2 but not always at the levels dictated by the standards for high pressure ratio (CF6-6) type engines. Control of the T1 and APU class engines may be impractical to implement.	NO_x (P2 Class Engines): This class generally complies with the NO_x standard at present. THC, CO: Controls to meet EPA standards can generally be available by 1979-1980 due to the relatively simple technology involved. These techniques can also be retrofitted if necessary. ((This EPA conclusion may be true for newer engines but is not apparent in Table A-7-1 from the same report. A total of 17 of the 38 engines in this table have a fair, poor, or unknown chance of meeting the 1979 controlled levels)).
4.	Rudey (1976) p. 3 p. 9	NO_x: The EPA standards are compared to levels from production engines as shown in Table A-7-2. Effective control of NO_x in addition to THC, CO, and smoke will require implementation of staged or variable geometry type combustors. These concepts have a high to very high development risk.	HC, CO, Smoke: Modification of conventional combustors (improved fuel atomization and fuel-air flow distribution) can effectively reduce THC, CO and smoke ((to levels of standards in Table A-7-2)) with a low development risk.

TABLE A-7 (CONT'D.)
TEST OF HYPOTHESIS H-7

CURRENT A/C ENGINE EMISSION STANDARDS ARE TOO STRINGENT

ARBITRARY ORDER	SELECTED REFERENCE	TRUE	FALSE
5.	Diehl (1978) Table II	CO, NO_x: Emission levels of current production engines are shown in Table A-7-3. Controls of about 70%-80% for THC, 50%-70% control for CO, 40%-60% control for NO_x and 20% control for smoke are needed to meet the EPA standard. Table A-7-4 and A-7-5 indicate the standards for CO and NO_x were not attained in this experimental combustor program, even with the advanced technology used which requires major modifications.	HC: Levels well below the original EPA 1979 and 1981 standards were attained in these experimental combustor *studies using advanced technology.*
6.	Mularz, Gleason, Dodds (1979) p. 61		HC, CO (Idle Thrust Only): Results from this NASA sponsored Low Power Emissions Reduction (LOPER) Program indicate all concepts studied were well below levels of the 1981 EPA standards. ((Because these are advanced concepts requiring extensive additional research, they cannot be implemented by the EPA deadline)).
7.	Mularz (1977) p. 652		HC, CO, NO_x, Smoke (Turboprop, Class P2 Engines Only): Results from this study within the NASA sponsored Pollution Reduction Technology Program (PRTP) demonstrate that advanced technology concepts can be used to meet levels of control in the 1979 and 1981 EPA emission standard. Figure A-7-1 illustrates results compared with EPA standards and program goals set 25% below EPA standards to allow for increase during combustor final development.
8.	Federal Register (1976)	Smoke (T3 Class Only): Compliance with smoke standards *are extended from* January 1, 1978 *to* January 1, 1985. Extension saves cost of $21 million by September 1, 1981 on an engine which will be replaced 3 years later due to an FAA noise rule.	
II. Hypothesis as related to the EPA aircraft engine emission standards proposed on March 24, 1978.			
9.	Jones, Diehl, et al. (1978)	This report includes results of the NASA sponsored Experimental Clean Combustor Program (ECCP) and Pollution Reduction Technology Program (PRTP). It was also the basis of the NASA public comments on the revised EPA standards proposed in 1978. Results are illustrated in Figure A-7-2 for current production combustors, advanced technology combustors (to meet the 1984 newly certified engine, NCE, standards) *and modified production combustors* (to meet the 1981 newly manufactured engines, NME, standards).	
	p. 18, Figure 10	CO: While production combustor modifications proved successful in meeting the 1981 standard for a T4 (JT8D-17 in Figure A-7-2a) engine, advanced technology combustors in the T2 class were not entirely successful. ((Additional development is apparently required and depends on the level of NO_x which must be simultaneously met)).	THC: Both modified production and advanced technology combustors are well below the 1981 NME and 1984 NCE standards. Smoke: The T4 class engine is very close to the smoke standard in all versions tested. The T2 class engines were well below the standard in the production engine but significantly worse in the advanced concept configuration. Minor combustor airflow rescheduling is judged adequate to achieve the desired levels.

TABLE A-7 (CONT'D.)
TEST OF HYPOTHESIS H-7

CURRENT A/C ENGINE EMISSION STANDARDS ARE TOO STRINGENT

ARBITRARY ORDER	SELECTED REFERENCE	TRUE	FALSE
	Jones, Diehl, et al. (Cont'd.) p. 18, 19, Figure 10	NO_x: Only one of three experimental engines was successful in meeting the 1984 NME and NCE standard. Engines in both the T2 and T4 classes were above standards.	
	p. 20, Figure 11		THC, CO, NO_x, Smoke (P2 Class Engine Only): A modified production combustor using reverse flow concepts easily demonstrated that the P2 proposed standards were realistic (Figure A-7-3). For this class of engines the NO_x standard was already higher than production combustor emissions. This allowed slight increases in NO_x to be traded for large decreases in HC, CO, and smoke levels with only minor combustor modifications.
10.	Jones (1978) p. 109 p. 104	NO_x, Smoke (With Low Quality Fuels): Future jet fuels may have to be refined from alternative sources such as shale oils, tar sands, and coals. Derived fuels are generally higher in sulfur fuel bound nitrogen, and trace elements than fuels from crude oil sources. With the present ASTM Jet-A fuel specification, aromatic concentrations are 20%, hydrogen contents are 13.7% and the atomic hydrogen/carbon ratio is 1.92. Lower quality fuels will have greater aromatics, and lower hydrogen content. The resulting lower hydrogen/carbon ratios increase the flame radiation levels and produce more smoke. Simultaneous control of smoke and NO_x will be extremely difficult even if the fuel-bound nitrogen can be removed at the refinery. ((Low quality fuels may require that advanced concept combustors be implemented for acceptable engine durability. Attainment of the EPA proposed standards, or even current emissions, is questionable under these conditions)).	
		References 11 to 14 below were submissions at the EPA public hearings on November 1 and 2, 1978 concerned with the EPA standards as proposed in 1978.	
11.	Pratt & Whitney Aircraft (1978)	CO: The 1981 EPA standards require a 70% reduction of CO. This reduction is too large and the compliance date too soon. The additional 30% reduction required in 1984 is not attainable.	HC (1981 Standard): The 1981 EPA standards require a 80%-90% reduction from present levels and is considered achievable. (See Figure A-7-4 and A-7-5).
	Titcomb, Chart 20-25 Goldberg, Charts 21-25, Chart 43, 44	NO_x: The 1984 regulation should be eliminated. The advanced technology concepts for NO_x reduction have major technical, logistical, and inventory problems. HC (1984 Standard): The additional 50% reduction from 1981 levels is not attainable.	Smoke: ((Standards are met for the JT8D-17 engine tested and nearly met for the JT9D-7F engine as per Figure A-7-4 and A-7-5)).

TABLE A-7 (CONT'D.)

TEST OF HYPOTHESIS H-7

CURRENT A/C ENGINE EMISSION STANDARDS ARE TOO STRINGENT

ARBITRARY ORDER	SELECTED REFERENCE	TRUE	FALSE
12.	Rolls Royce Ltd. (1978) p. 7, p. 2	NO_x (1984 Standard): While some NO_x reductions have been experimentally shown, the availability of technology to the degree required by these standards has not been demonstrated, particularly with simultaneous HC, CO, and smoke controls.	HC, CO (1981 Standard): Large reductions, 80% or more, of HC and CO could be put into service. (However, this degree of severity which requires complex new control systems such as sector burning is both unjustified and unnecessary.)
13.	Societe Nationale D'Etude et de Construction deMoteurs D'Aviation (SNECMA) (1978) pp. 3-6	CO (1981 Standard): Proposed levels are below attainable limits (see Figure A-7-7). NO_x: *Firm support is given* to an adequate NO_x regulation based on available technology, even *as early* as 1981. The 1984 proposed EPA standard is not achievable but other levels are recommended (see Figure A-7-8). A NO_x limiting level ((standard)) is endorsed to avoid simply oversizing the combustor to achieve a longer residence time for CO and THC control.	HC (1981 Standard): Proposed levels are within attainable limits (see Figure A-7-6). Smoke: The levels in the EPA standards are in agreement with ICAO levels and are generally accepted by the manufacturers.
14.	Riehl, Boeing Commercial Airplane Company (1978) p. 11	NO_x: The technology for NO_x control does not exist. CO: Standards can not be met on *operationally acceptable* combustors. Sector burning is required to meet CO and HC standards simultaneously *and will adversely* affect aircraft reliability.	

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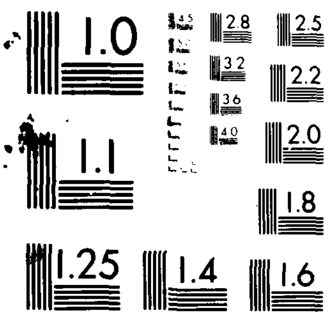


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

TABLE A-7-1

PROSPECTS OF MEETING THE AIRCRAFT ENGINE EMISSION STANDARDS (SOURCE: Munt, 1976)

Engine	HC and CO prospects** 1979	1980	1981	later	NO_x prospects** 1980	1981	1982	1983	later
T1 Class (small jet engines)									
1. AiResearch									
TFE731	good						good		
ATF3	unknown				unknown				
2. Pratt & Whitney of Canada									
JT15D		fair					fair		
3. Avco-Lycoming									
ALF502	fair						good		
4. General Electric									
CJ610	poor----------	----------	----------	----------	already met				
CF700	poor----------	----------	----------	----------	already met				
5. Pratt and Whitney									
JT12A	poor----------	----------	----------	----------	already met				
6. Rolls Royce									
M45H		good			good				
RB401	good				good(1979)				
T2, T3, T4 Classes (large jet engines)									
1. Pratt and Whitney									
JT9D-7		good					good		
JT9D-70		good							good
JT10D	good at certification date				good at certification date				
JT3D	poor----------	----------	----------	----------	poor----------	----------	----------	----------	----------
JT8D		fair			poor----------	----------	----------	----------	----------
2. General Electric									
CF6-6	good				poor----------	----------	*----------	----------	----------
CF6-50	fair				poor----------	----------	----------	*----------	----------
CFM56	fair							good	
3. Rolls Royce									
RB211-22B		fair			good (date unknown)				
RB211-524		good			good (date unknown)				
Spey511	poor----------	----------	----------	----------	unknown				
Spey555	poor----------	----------	----------	----------	unknown				
P2 Class (turboprop engines)									
1. AiResearch									
TPE331	good				already met				
2. Pratt and Whitney of Canada									
PT6A-27		good			already met				
PT6A-41		good			already met				
3. Avco-Lycoming									
LTP101	fair	good			good (1979)				
T5321A	already met				already met				
PLT27	already met				already met				
4. Allison									
250		good			already met				
501			good		already met				
5. Rolls Royce									
Dart		fair			good				
Tyne	unknown				unknown				
APU Class (on board power)									
1. AiResearch									
GTCP85	good				poor----------	----------	----------	----------	----------
TSCP700	already met					good			
GTCP36	good				unknown				
GTCP30	already met				unknown				
GTCP660		good			poor----------	----------	----------	----------	----------
2. Pratt & Whitney of Canada									
ST6	already met					good			
3. Solar									
Titan-39	unknown				unknown				

* GE NO_x technology available but inadequate for compliance.

** Prospects for meeting the existing levels specified by the EPA 1979 standards for newly manufactured engines by January 1 of the indicated year.

TABLE A-7-2

EPA PARAMETER EMISSION LEVELS FOR THE LTO CYCLE

(SOURCE: Rudy, 1976)

1979 EPA STANDARDS

*ENG CLASS	THC		CO		NO_x		SMOKE	
	PRES	STD	PRES	STD	PRES	STD	PRES	STD
T1	4-16	1.6	15-60	9.4	2.5-4.5	3.7	-----	<32
T2, T3, T4	2-21	.8	7-20	4.3	3-10	3.0	20-65	<25
P2	6-12	4.9	20-30	26.8	6-10	12.9	-----	<50
PISTON	3-4.5	1.9	50-120	42	0.2-1.3	1.5	-----	---
1981 EPA STANDARDS								
T2, T3, T4	2-21	0.4	7-20	3.0	3-10	3.0	20-65	<25

*T1 - JET AIRCRAFT GAS TURBINE ENGINES, <8000 LB THRUST.
T2 - JET AIRCRAFT GAS TURBINE ENGINES, >8000 LB THRUST.
T3 - JT3D ENGINES.
T4 - JT8D ENGINES.
P2 - TURBOPROP AIRCRAFT GAS TURBINE ENGINES.

TABLE A-7-3

PRODUCTION ENGINES VERSUS
1979 EPA STANDARD

(SOURCE: Diehl, 1978)

ENGINE CLASS	ENGINE	THC		CO		NO_x		SMOKE	
		STD	PROD	STD	PROD	STD	PROD	STD	PROD
P2	501-D22A	4.9	306	26.8	118	12.9	48	29	189
T1	TFE-731	1.6	331	9.4	180	3.7	162	40	118
T4	JT8D-17	.8	500	4.3	356	3.0	260	25	120
T2	JT9D-7	.8	488	4.3	198	3.0	197	20	50
T2	CF6-50	.8	538	4.3	251	3.0	257	19	68

PRODUCTION VALUES AS % OF EPA STANDARD.

TABLE A-7-4

POLLUTION SUMMARY ALL ENGINE CLASSES

(SOURCE: Diehl, 1978)

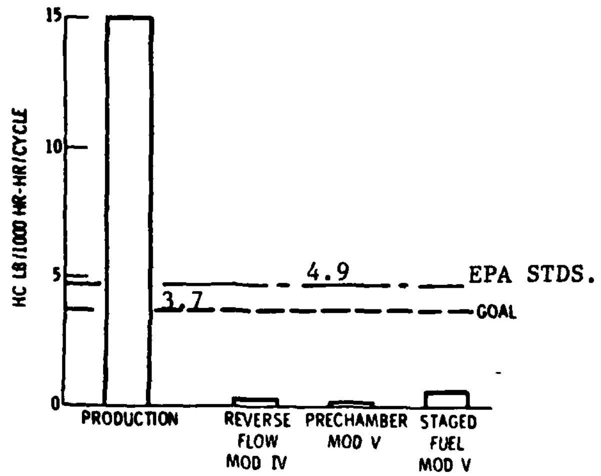
EPA CLASS	ENGINE	ENGINE PR	MODIFICATION REQ'D	% OF 1979 EPA STD			
				THC	CO	NO_x	SMOKE
P-2	501-D22A	9.7	MINOR	6	17	57	59
T-1	TFE731-2	13	MAJOR	25	107	100	---
T-4	JT8D-17	17	MAJOR	25	207	146	108
T-2	JT9D-7	22	MAJOR	25	74	90	150
T-2	CF6-50	30	MAJOR	38	77-147	147-187	132

TABLE A-7-5

POLLUTION SUMMARY
T2 ENGINE CLASS

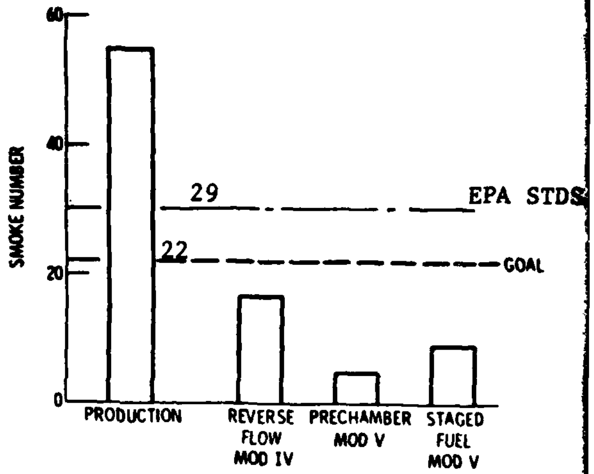
(SOURCE: Diehl, 1978)

ENGINE	% OF 1981 EPA STD		
	THC	CO	NO_x
JT9D-7	50	106	90
CF6-50	76	110-211	147-187



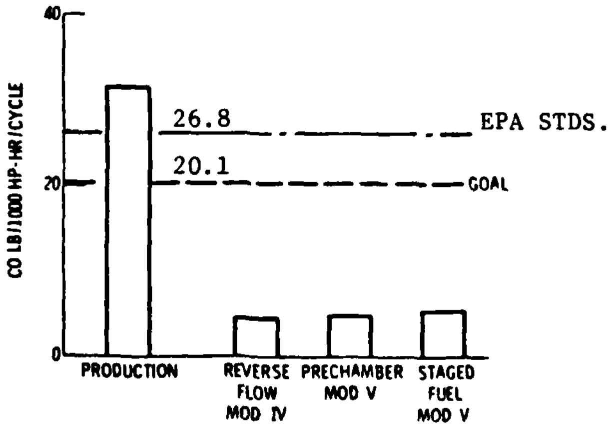
Comparison of hydrocarbon emissions from best combustor concepts and from production combustor.

(a) Hydrocarbon Emissions



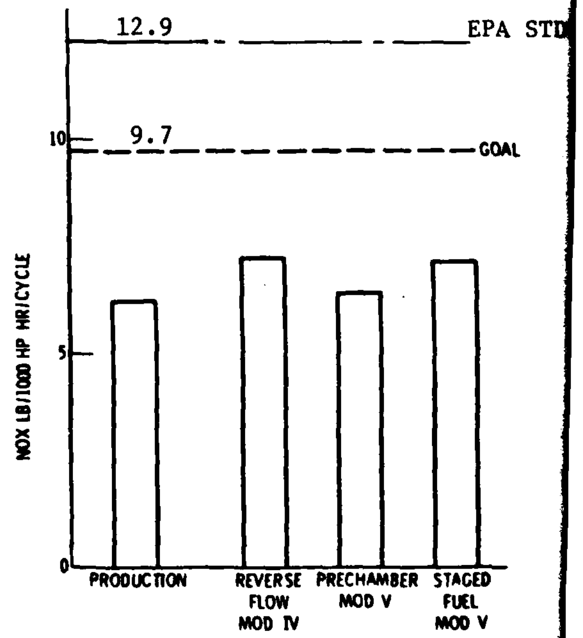
Comparison of smoke emissions from best combustor concepts and from production combustor.

(c) Smoke Emissions



Comparison of carbon monoxide emissions from best combustor concepts and from production combustor.

(b) Carbon Monoxide Emissions



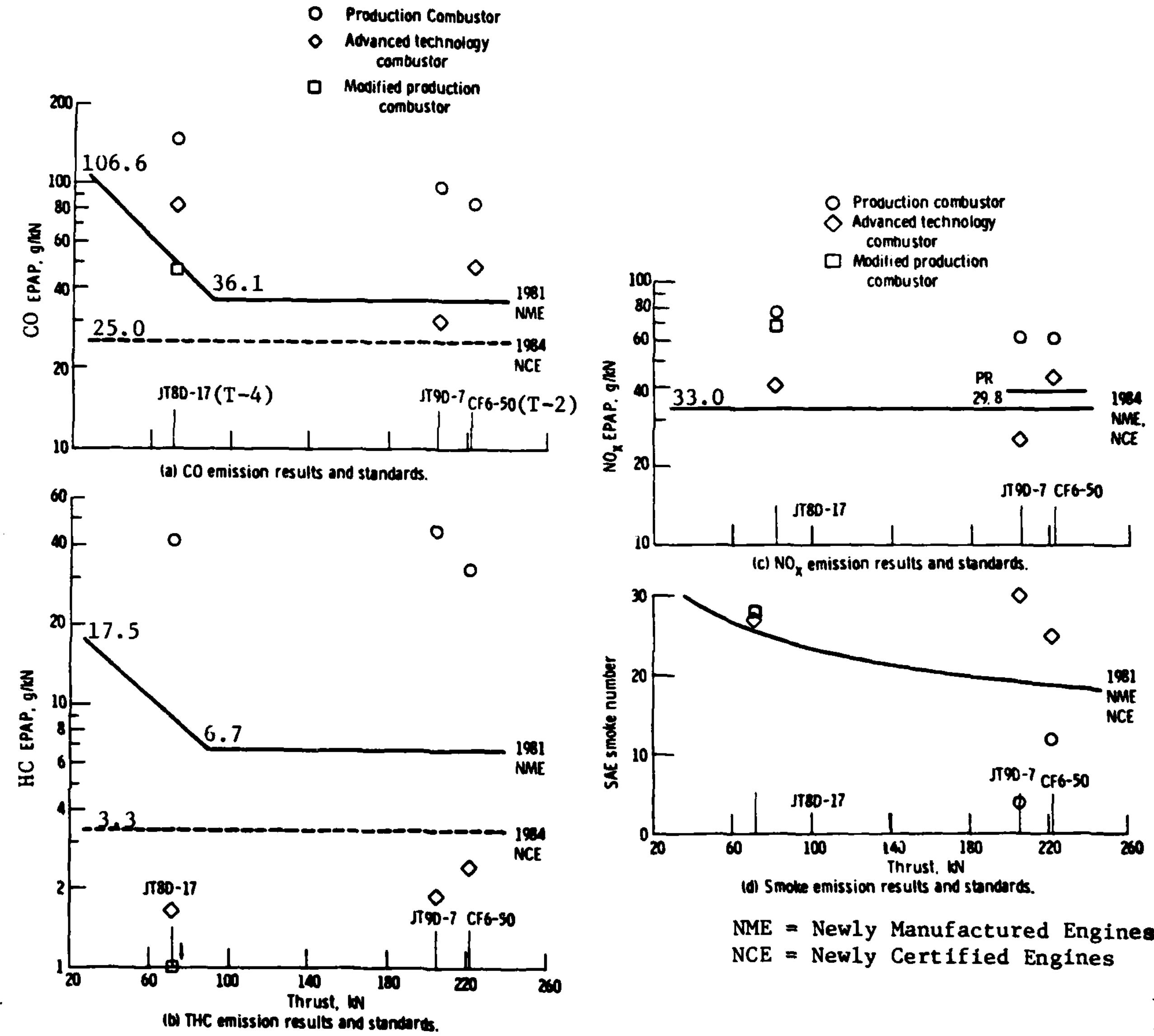
Comparison of oxides of nitrogen emissions from best combustor concepts and from production combustor.

(d) Oxides of Nitrogen Emissions

(SOURCE: Mularz, Gleason, Dodds, 1979)

FIGURE A-7-1

COMPARISON OF POLLUTANT EMISSIONS FROM ADVANCED TURBOPROP COMBUSTOR CONCEPTS WITH PRODUCTION COMBUSTORS AND EPA STANDARDS FOR 1979. The NASA program goals shown were set 25% below EPA standards to allow an increase during final combustor development.

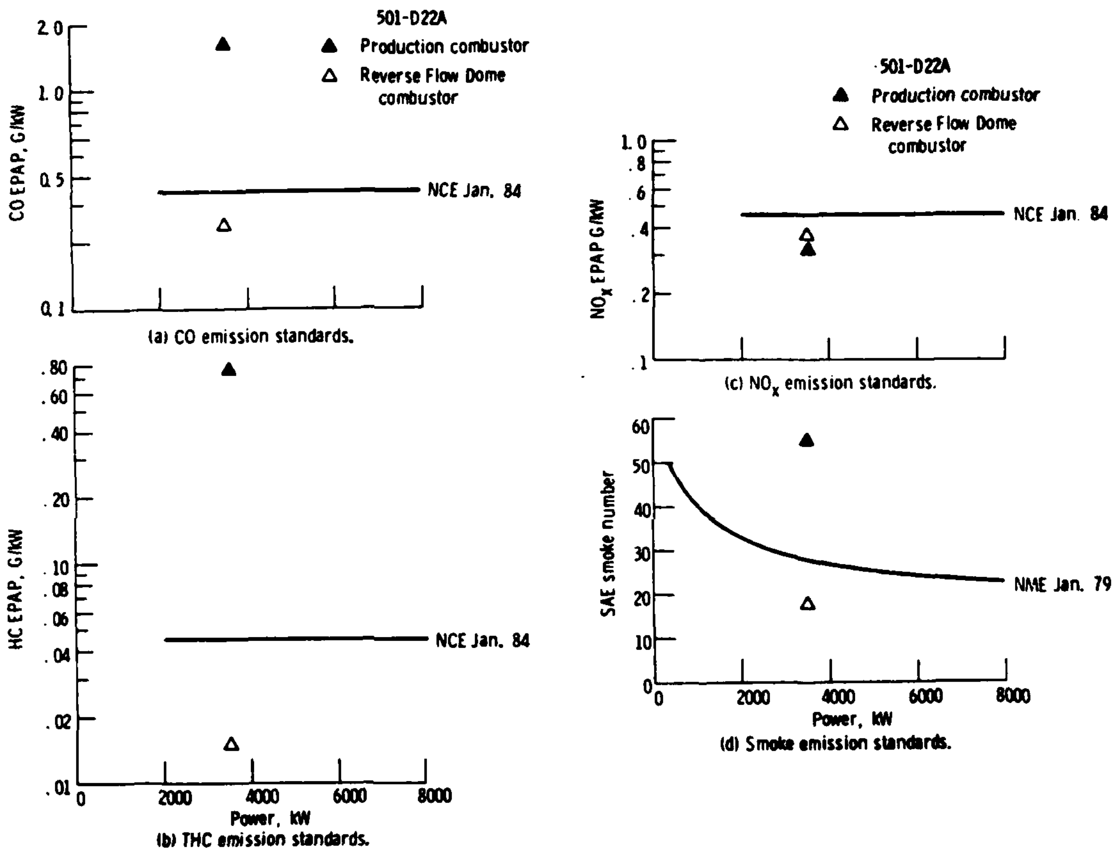


NME = Newly Manufactured Engines
NCE = Newly Certified Engines

(SOURCE: Jones, Diehl, et al., 1978)

FIGURE A-7-2

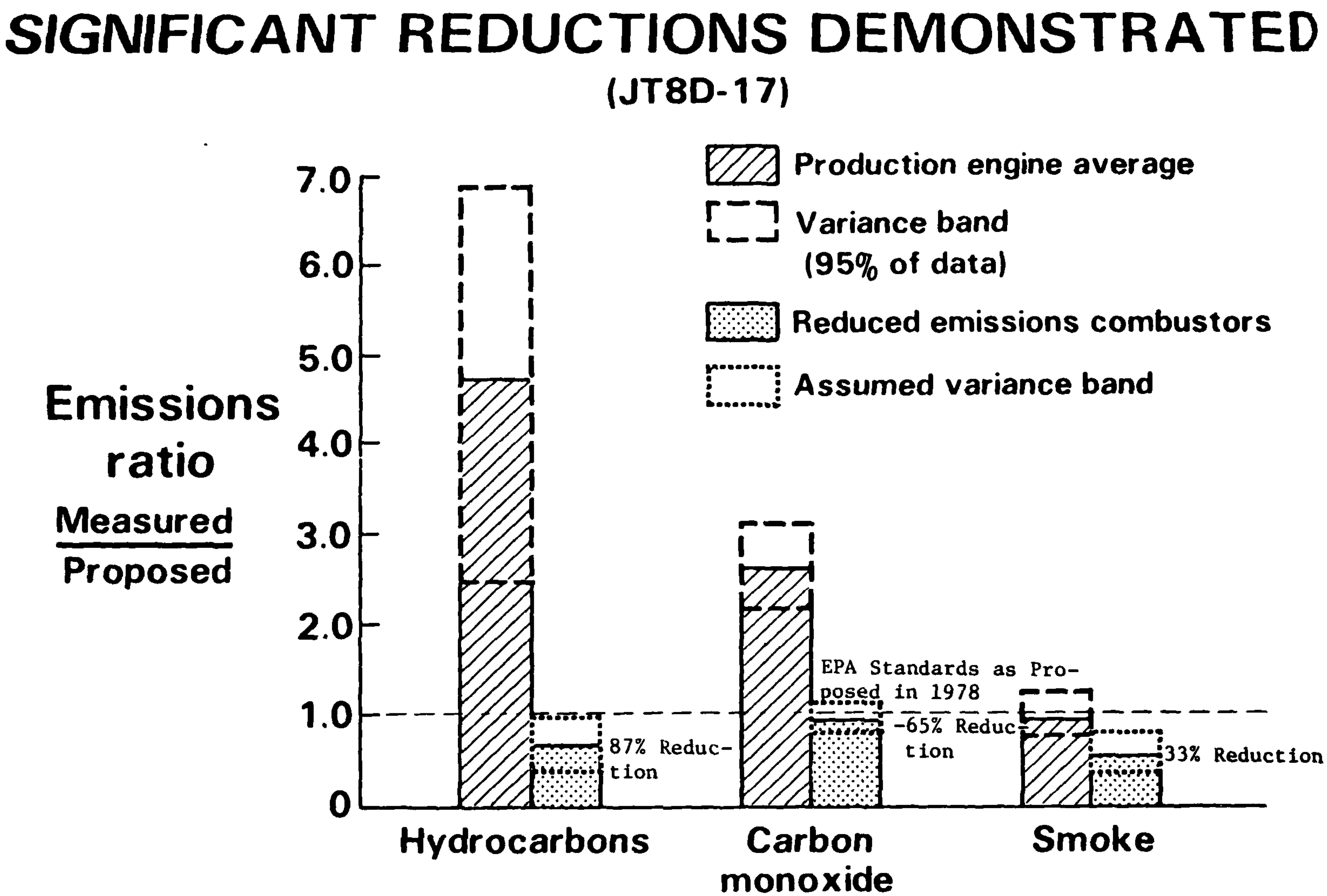
COMPARISON OF PRODUCTION, MODIFIED PRODUCTION, AND ADVANCED TECHNOLOGY COMBUSTORS WITH EPA (1978-PROPOSED) STANDARDS



(SOURCE: Jones, Diehl, et al., 1978)

TURBOPROP CLASS ENGINE EMISSIONS COMPARED TO EPA STANDARDS PROPOSED FOR 1984

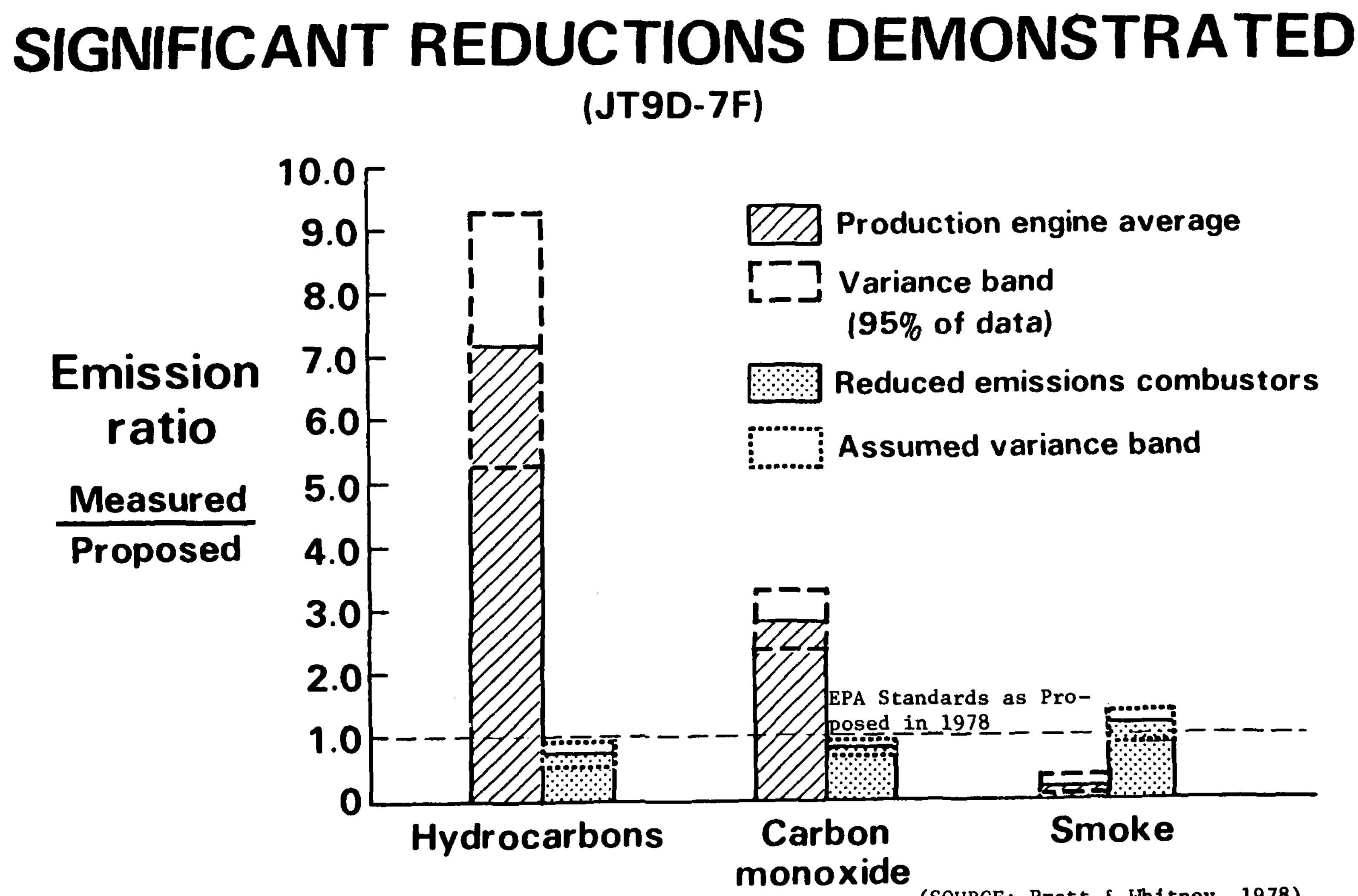
FIGURE A-7-3



(SOURCE: Pratt & Whitney, 1978)

POTENTIAL EMISSION REDUCTIONS FROM A JT8D-17 ENGINE

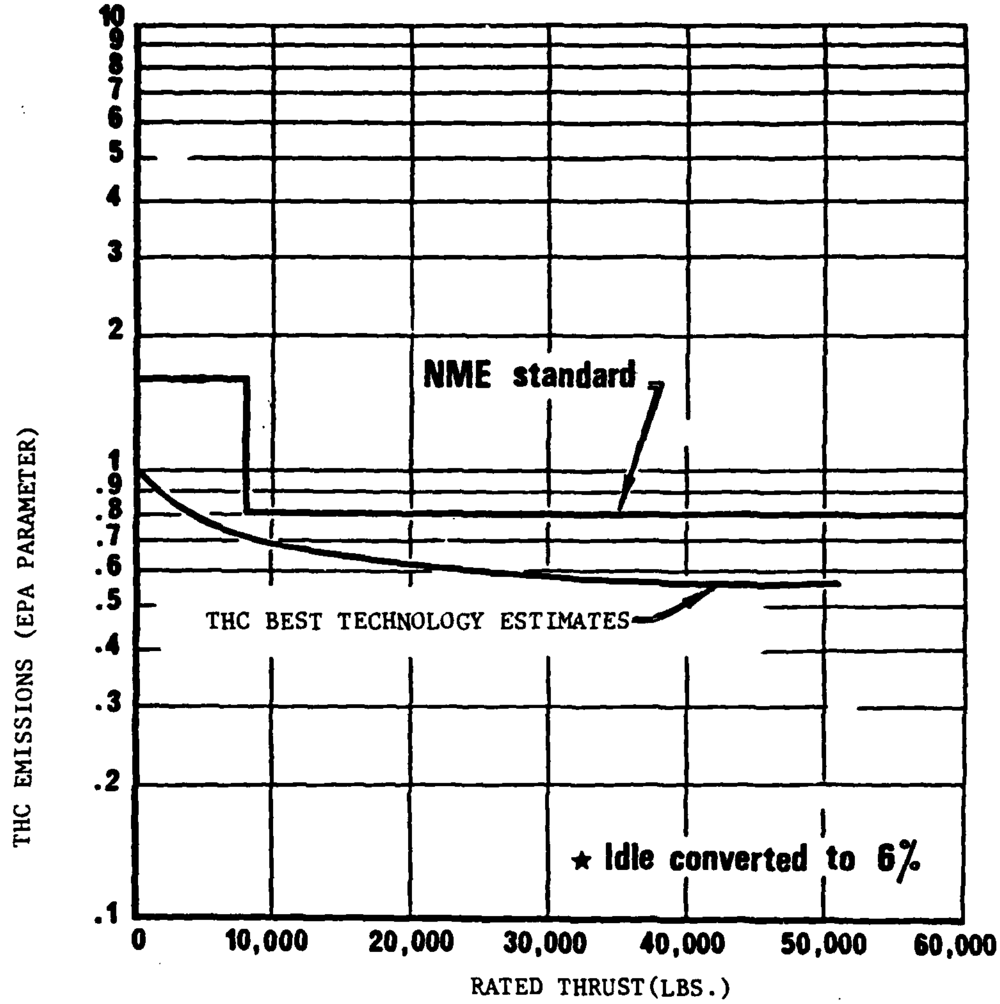
FIGURE A-7-4



(SOURCE: Pratt & Whitney, 1978)

POTENTIAL EMISSION REDUCTIONS FROM A JT9D-7F ENGINE

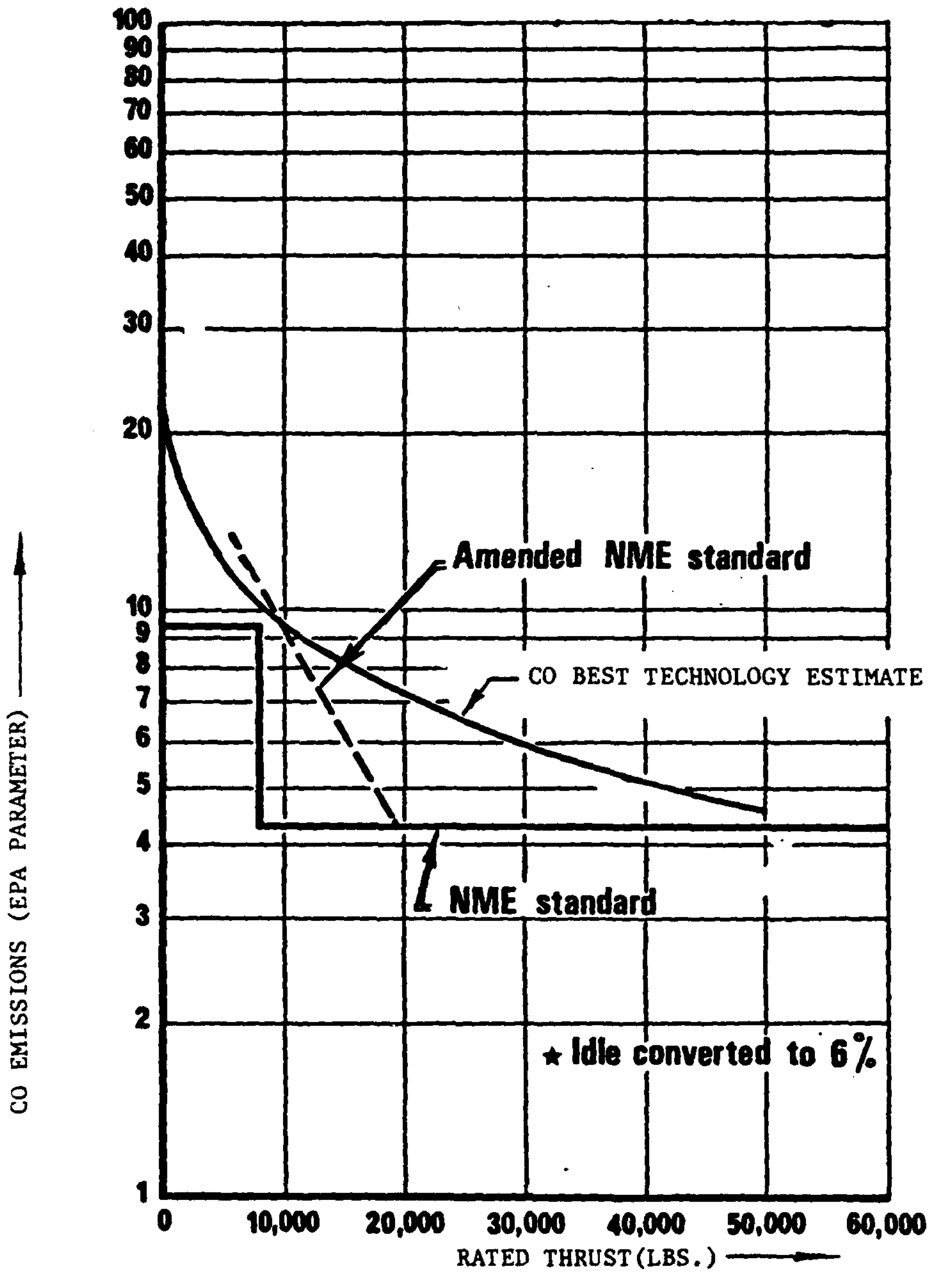
FIGURE A-7-5



(SOURCE: SNECMA, 1978 based on data in Munt, 1976)

PROPOSED THC STANDARDS COMPARED WITH BEST TECHNOLOGY ESTIMATES

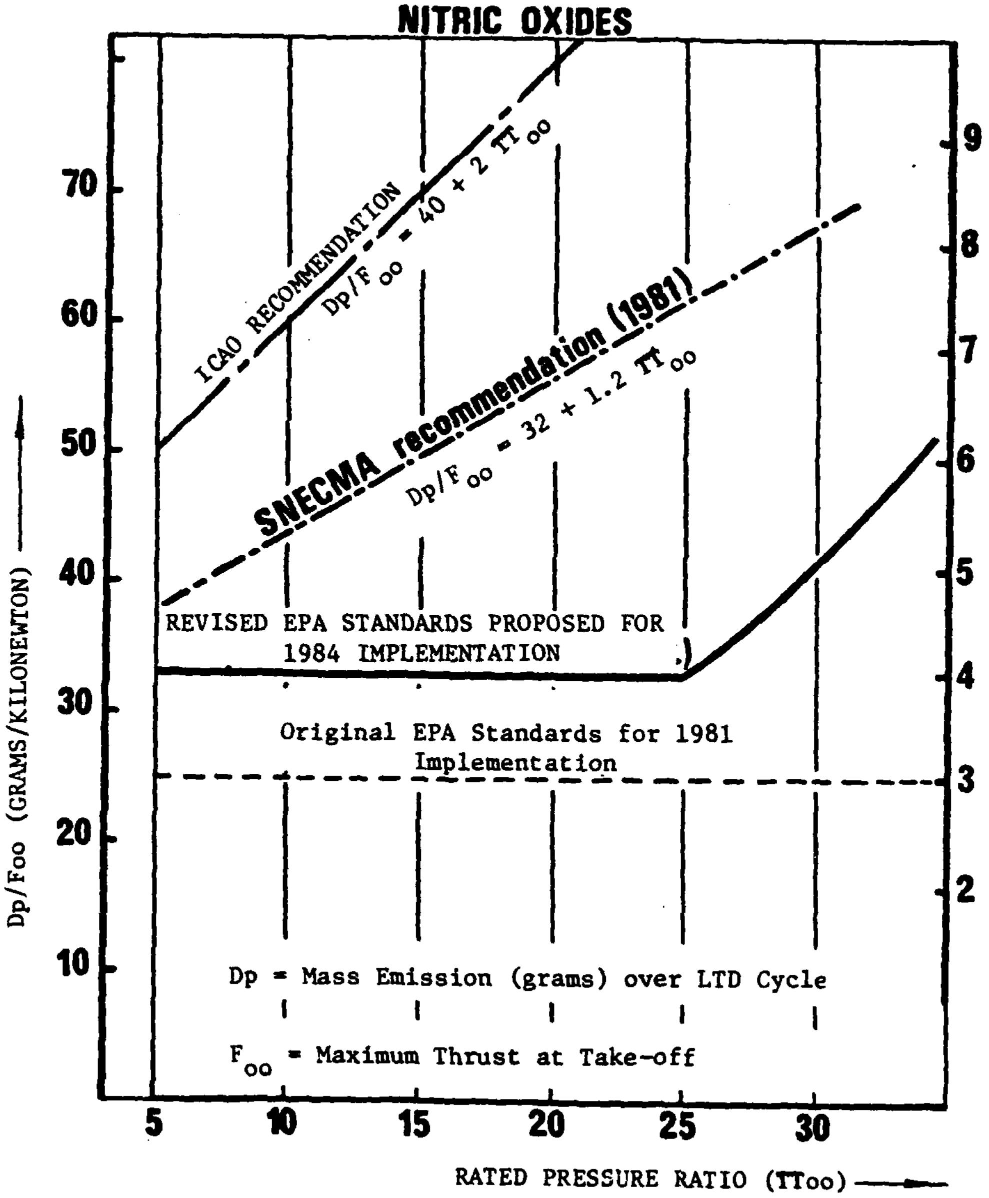
FIGURE A-7-6



(SOURCE: SNECMA (1978) with modifications to include ICAO Recommendations)

PROPOSED CO STANDARDS COMPARED TO BEST TECHNOLOGY ESTIMATES

FIGURE A-7-7



(SOURCE: SNECMA (1978) with modifications to include ICAO Recommendations)

NO_x STANDARDS AS RECOMMENDED BY SNECMA (CLASSES T1, T2, T3, and T4)

FIGURE A-7-8

APPENDIX SECTION A.8

TEST OF HYPOTHESIS H-8

Hypothesis H-8: "Aircraft controls should not be set solely on judgements of best available control technology".

Issues: The establishment of emission standards at levels representing the best available control technology makes sense if the maximum emission reductions with few economic constraints can be justified. Sources which emit hazardous pollutants with known serious health effects may fall into this category. Conversely, where maximum controls are not required, other techniques which balance air quality benefits with economic or other objectives may be preferable. Aviation sources appear to fall into the latter category since the air quality benefits from controls are debatable and the costs are not trivial.

Discussion: Several aviation standard setting techniques which can be considered alternatives to best available control technology (BACT) are discussed in Chapter VIII. As illustrated in Table VIII-5, these techniques can suggest quite different levels of control and requirements for control. For example, CO controls are technologically feasible but may have little environmental benefit (from emission comparisons, rollback, and event trees) and are slightly less cost effective than other control strategies now under serious consideration. Some NO_x control is possible (BACT, or more properly in this case, best advanced control technology) but is well above the cost effectiveness of other strategies.

The way that standard setting judgements are made depends on the relative weights given to each technique.

The preference toward basic policy objectives is illustrated below:

Environmental Objective Preference	Multi Objective Preference	Economic Objective Preference
BACT	Combination of Various Standard Setting Techniques	Cost Effectiveness

The issue of whether aviation standards should be set solely using a BACT technique is therefore a policy question, not a technical one. A rigorous political science or social science analysis is beyond the scope of this work. Instead the recently released National Commission on Air Quality (NCAQ) report is used as an indicator of what past policy has been and perhaps what it should be.

The commission's general conclusion is that the structure of the Clean Air Act is sound and that refinements, rather than fundamental changes, are needed (NCAQ, 1981, p. 1-8). One observation is that (NCAQ, 1981, p. 1-6):

> "The structure of the Clean Air Act--as it was enacted in 1970 and modified in 1977-- provided the framework for the commission's research activities. While the cornerstone of the Act's requirements are the provisions providing for the establishment of national ambient air quality standards to protect public health and public welfare, the Act includes specific technology requirements that also must be met regardless of whether they are necessary to meet specific air quality standards. This structure reflects a decision by Congress to combine the two general approaches available for addressing pollution problems--a goals-oriented approach and a technology-based one, rather than rely on either one alone".

The technology-based approach appears to be most appropriate for sources of hazardous pollutants and for new source performance standards.

Application to aviation sources suggests that the BACT approach alone is adequate. The NAAQS approach applied to aviation sources suggests that either no controls are warranted or that only THC and perhaps NO_x controls are warranted due to their possible implication in O_x violations.

EPA is not expected to add NAAQS for additional pollutants but will continue to refine and revise standards for pollutants already regulated. The costs of meeting NAAQS should not be considered in the standard itself but in how control programs are implemented in specific areas of the country (NCAQ, 1981, p. 2.1-2). A balance between air quality objectives in severely polluted areas and the economic, social, energy and other costs in meeting those objectives are suggested.

The Clean Air Act gives EPA sole responsibility for control of new mobile sources. EPA and the state/local governments share in the control of in-use motor vehicles (NCAQ, 1981, p. 2.1-10). This concept appears to apply to aircraft as well as motor vehicles except that the U.S. Federal Aviation Administration is also responsible for all safety concerns. Aircraft towing rather than taxiing is an example where in-use control strategies could be devised on a local basis. The FAA concerns about potential flight safety problems would first have to be resolved, however. Most states rely on the Federal control of emissions from cars rather than on in-use transportation controls (NCAQ, 1981, p. 2.1-21). If this experience can be extrapolated to aircraft, emission reductions from towing or other in-use strategies would be low. Federally mandated strategies in certain airports or cost savings from fuel costs could reverse this projection.

Some aspects of the Federal new source performance standards (NSPS) are of interest even though in a different part of the Clean Air Act from aircraft. New source performance standards adopted by EPA generally require the use of good controls but not necessarily the technology that would result in the lowest possible emission levels (NCAQ, 1981, p. 2.1-64). There is some indication that this same philosophy has been considered by EPA for aircraft controls. A letter from the EPA Office of Air Quality Planning and Standards to the Assistant Administrator for Air and Waste Management (Barber, 1977) argues that some form of NO_x control will be needed on newly designed aircraft engines but that they should be in line with the cost effectiveness of other sources of similar size. The precedent has been established to set a NSPS level which was cost effective rather than set solely on the BACT approach.

Conclusions: Other emission standard setting techniques in addition to maximum technological control appear to provide additional information to help determine a balance among air quality, economic and other objectives. The need for this balance appears to be suggested in the Report of the National Commission on Air Quality. This could lead (or perhaps reflect) a trend away from strict environmental constraints and toward approaches based on economic efficiency. The conclusion that alternative techniques, in addition maximum control technology, should be used to establish aviation emission standards is assumed throughout this work. This assumption is necessary since the determination of how emission standards should be established is a policy question rather than a technical question.

APPENDIX A.9

(NOT INCLUDED - NO TEST
OF HYPOTHESIS H-9 NEEDED)

APPENDIX SECTION A.10

TEST OF HYPOTHESIS H-10

Hypothesis H-10: "A combination of national and local option control strategies are best".

Issues: Both national and local aviation control strategies may be preferable to only national controls. This allows an increase in the total emission reductions or less stringent national controls supplemented by localized controls as needed. The energy and environmental benefits of localized strategies, such as aircraft towing, must be weighed against safety and economic concerns.

Discussion: National aviation control strategies dealing with aircraft engine redesign are analyzed in H-4 and H-7. A number of alternative strategies have been proposed and will be discussed in this Appendix. Strategies considered are as follows:

1. Engine Shutdown: Since most of the THC and CO emissions are during aircraft taxi/idle operations, a shutdown of some of the engines (e.g. 2 engines in a 4 engine aircraft) can have a large potential benefit. The remaining engines operate in a higher, more efficient range which further reduces emissions. Gate hold procedures which minimize taxi times are also included in this category in the tables in this Appendix.
2. Aircraft Towing: The towing of aircraft between active runways and the terminal gate area would eliminate most aircraft taxi emissions. Specially designed Diesel tow tractors would produce low emissions and a considerable fuel savings. Like engine shutdown, towing could be implemented according to the local needs for emission control.

3. Fleet Mix: A higher percentage of wide-body aircraft in the fleet would allow fewer take-offs and landings. This would lower the per passenger emissions at an airport.
4. Capacity Control: A strategy which imposes a higher passenger load factor in any type of aircraft could also reduce the number of aircraft operations. As with the fleet mix strategy, controls could not be imposed at a single airport but would require carefully planned routing for a number of major airports.
5. Airport Design Configurations: Airports could theoretically be designed to minimize aircraft taxi times, aircraft parking densities, and ground motor vehicle densities. Aircraft tow tractor staging areas and return pathways could be designed.

As concluded in H-6, only THC and CO reductions are feasible with alternative control strategies. Aircraft controls for NO_x and smoke must involve engine redesign. Since aviation controls for CO do not produce a significant air quality benefit (see H-5), the evaluation of strategies in this hypothesis will focus on THC.

Data Evaluation: Data to evaluate this hypothesis are quite weak since controls which could be implemented on a local basis have never been used in practice. Only two studies were found which evaluate alternative aviation emission control strategies including both national and local option possibilities. Results of those studies and comparisons from this work are shown in Table A-9.

The test of this hypothesis is to determine if some combination of national and local option control strategies are best in the development of aviation emission controls. Three criteria, emission benefit, cost of control, and implementation difficulty, are used to make the judgement of which strategies are "best". The emission benefits from various strategies at 20 of the most active airports in the U.S. are shown in Table A-9-1. Over half of the U.S. commercial air carrier operations are at these airports. Aircraft engine emission controls offer the largest potential emission benefits. Aircraft towing, fleet mix, and to a lesser degree, engine shutdown, also promise significant emission reductions.

The costs of aviation control strategies are compared in Table A-9-2. Estimated costs for capacity control, fleet mix and airport design configuration strategies could not be found. Modified ground operations such as towing and engine shutdown are clearly cost-effective with large net savings rather than costs. As illustrated in this table, projected increases in jet fuel costs from $1.00 to $1.50 per gallon greatly increase this savings potential. Aircraft engine standards have costs, rather than savings, per ton of THC eliminated. These costs are typically $200 to $500 per ton and are in the range of other non-aviation emission control strategies being implemented by EPA.

Findings: A summary of these costs and benefits plus a description of the difficulty of strategy implementation are presented in Table A-9-3. Aircraft engine controls offer the largest emission benefits but also the largest control costs. Implementation is logistically easier due to the small number of engine manufacturers compared to the large number of airports where other strategies would have to be implemented. This could be one reason why other more cost-effective strategies have been largely overlooked.

Aircraft towing and engine shutdown are attractive strategies if the implementation difficulties can be overcome (see H-11). The severe difficulty in implementation of the fleet mix, capacity control and airport design strategies make their adoption highly unlikely. The difficulties are more organizational than technological. The limited emission benefits would hardly justify the vast Federal organization for the planning and control of these strategies.

Conclusions: Combinations of national and local aviation control strategies are concluded to be better than either type alone. National strategies are effective, can be implemented with minimal difficulty, but have significant cost penalties. Local option controls such as aircraft towing or engine shutdown can reduce THC emissions at an airport by hundreds of tons per year at a cost savings of perhaps a million dollars per year per airport. Pollution control strategies rarely offer simultaneous energy, environmental, and economic benefits. Safety and operational concerns associated with these strategies have never been resolved; nor have they been confirmed. A much more aggressive program than has been seen over the past eight years is therefore recommended in order to demonstrate the practicality of these local option control strategies.

TABLE A-10

TEST OF HYPOTHESIS H-10

A COMBINATION OF NATIONAL AND LOCAL CONTROLS ARE BEST

ARBITRARY ORDER	REFERENCE	TRUE	FALSE
0.	This Work	Hundreds to thousands of tons per year of THC emission reductions are *theoretically* possible with *local* as well as national control strategies. (See Table A-9-1). Towing and fleet mix are cost effective strategies with potential savings of roughly *$3,000 to $9,000 per ton of THC eliminated*. (See Table A-9-2). Control of aircraft engine emissions typically cost several hundreds of dollars per ton of THC and are in the same range as other pollution control strategies. Some engine types can run up to several thousands of dollars per ton, however. Potential difficulties in implementation of control strategies are suggested in Table A-9-3. While the fleet mix strategy offers potentially large emission reductions, there are unknown cost penalties and implementation is judged to be very difficult. Implementation of aircraft towing may be difficult due to safety concerns (see H-11).	
1.	Cirillo (1975)	Extensive computer modelling of the Atlanta Airport was used to evaluate many alternative control strategies to reduce aircraft emissions. Conclusions are as follows:	
	p. 163	Towing, engine emission standards, and fleet mix controls provide the greatest THC and CO air quality improvements, in that order. Engine shutdown and capacity control provide only small improvements. ((Only a small percentage of the aircraft were assumed to practice engine shutdown in this model in order to simulate operations in the Atlanta airport field test. Potential emissions reductions may be much greater)).	
2.	EPA (1972) p. 6	The development of new combustor technology and the modification of aircraft ground operational procedures were both found to be feasible. *Modification of ground procedures at the Los Angeles airport were estimated to cause the following THC reductions:*	
	p. 74	1. Aircraft Towing..............................58% 2. One Engine Taxi (engine shutdown).............49% 3. Two Engine Taxi (engine shutdown).............34% 4. Gate hold to Eliminate Delays................. 9% 5. Increase Engine Idle Speed.................... 7% 6. Transport Passengers between Terminal and Airport.................................... 3% 7. Shutdown of Auxiliary Power Unit.............. 2%	

TABLE A-10-1

EMISSION BENEFITS FROM AVIATION CONTROL STRATEGIES

Airport	Aircraft THC Emissions -1980 Data(1) (1000 Tons THC/Yr)	THC Emissions Reduction-1000 M/Tons THC/Yr (% Reduction) Engine Controls(2)	Towing(3)	Engine Shutdown(4)	Fleet Mix(5)	Capacity Control(6)
Atlanta	2.45	1.72 (70%)	1.05 (43%)	.9 (35%)	1.4 (56%)	.3 (12%)
Boston	1.80	1.26	.77 (43%)	.6	1.0	.2
Chicago O'Hare	6.65	4.66	4.73 (71%)	2.3	3.7	.8
Dallas/Fort Worth	1.75	1.23	1.02 (58%)	.6	1.0	.2
Denver	0.91	.64	.87 (96%)	.3	.5	.1
Honolulu	2.15	1.51	.39 (18%)	.8	1.2	.3
Houston	1.02	.71	.23 (23%)	.4	.6	.1
Los Angeles	4.93	3.45	2.18 (44%)	1.7	2.8	.6
Miami	2.21	1.55	.80 (36%)	.8	1.2	.3
Minneapolis-St. Paul	0.65	.46	.13 (20%)	.2	.4	.1
New York-Kennedy	6.44	4.51	4.66 (72%)	2.3	3.6	.8
New York-LaGuardia	1.19	.83	.35 (29%)	.4	.7	.1
Philadelphia	1.14	.80	.49 (43%)	.4	.6	.1
Pittsburgh	0.55	.39	.30 (55%)	.2	.3	.1
St. Louis	1.10	.77	.65 (59%)	.4	.6	.1
San Francisco	2.90	2.03	1.40 (48%)	1.0	1.6	.4
Seattle-Tacoma	0.93	.65	.28 (30%)	.3	.5	.1
Tampa	0.93	.65	.19 (20%)	.3	.5	.1
Washington,D.C.-National	0.55	.39	.15 (27%)	.2	.3	.1
TOTAL	40.15	28.21 (70%)	20.64 (51%)	14.1 (35%)	22.5 (56%)	4.9 (12%)

(1) Bauchspies, James, Unpublished data from FAA Airport Emissions Data Base, produced under FAA contract by ORI, Inc., May 1, 1981.

(2) Control reductions are estimated at 80%. Reductions between 70% and 90% appear technologically possible (conclusion of Hypothesis H-4).

(3) Reductions based on detailed study in "Aircraft Towing..."(1980) proposed by Peat, Marwick, Mitchell & Co. under U.S. DOE contract.

(4) Estimate of 35% by this author. Other estimates are 50% in Gelinas (1979), 21%-48% in Sampson (1974), 7% based on the test program at the Atlanta airport in Cirillo (1975), and 34%-49% in EPA (1972).

(5) Estimate of 56% based on projected wide-body aircraft increases in Cirillo (1975). Large over-estimate quite possible.

TABLE A-10-2
COSTS OF AVIATION CONTROL STRATEGIES

Reference	Control Strategy	*U.S. Control Costs** or (Savings) ($ million/year)	Cost Effectiveness* ($/Ton THC Eliminated)
A. Modified Ground Operations			
1. "Aircraft Towing... (1980)	Towing -$1/gal jet fuel	(80)	(3857)**
	-$1.50/gal jet fuel	(193)	(9306)**
2. Sampson (1974)	Engine Shutdown plus Gate Hold	(20) to (30)**	(3355)**
3. EPA...NPRM (Dec. 12, 1972)	Any Type of "Ground Operations"	(10)	
4. Horowitz (Jan. 1972)	Engine Shutdown		
	-EPA Estimates	(55)	
	-FAA	(8)	
	-United Air Lines	(12)	
	-Eastern(FAA Projection)	(5)	
B. Aircraft Engine Emission Standards			
1. Wilcox (Dec. 1979)	1981NME + 1985IUE	188	200
2. Pratt & Whitney (1978)	1981NME for JT-8D		200**
	for JT-9D		800**
	1985IUE for JT-8D		1300**
	for JT-9D		2400**
3. General Electric (1978)	1981NME + 1985IUE	750 to 1160	
4. Schneider (1973) (EPA is Source)	All 1973 Standards	141	
5. Day, Bertrand (1978)	1981NME + 1985IUE	455 to 631	
6. EPA...NPRM (1978)	1981NME		560
	1985IUE		390
7. ICAO, WGA (1980)	1981NME + 1985IUE	1400	

*(...) = Net savings after capital improvement. equipment, manpower and maintenance costs were deducted.
**Costs estimated by this author based on data in reference as shown.

TABLE A-10-3
EVALUATION OF AVIATION EMISSION CONTROL STRATEGIES

Control Strategy	Emission Benefit	Cost (or Savings) of Control	Implementation Difficulty[1]
1. Engine Control Standards	Large	Moderate Costs (Generally in line with non-aviation THC control strategies	Small difficulty compared to other strategies: Implementation depends on small numbers of engine and air frame manufacturers. The concepts for control have generally been developed. Certification procedures are needed.
2. Aircraft Towing	Large	Large Savings	Large difficulty: High speed tractors must be purchased, operational procedures developed, tractor return pathways created, and safety concerns resolved prior to implementation. Both energy and emission benefits are strong incentives to thoroughly test this alternative.
3. Engine Shutdown	Moderate	Moderate Savings	Moderate difficulty: Requirements to taxi aircraft on fewer engines or to hold at the gates until ready for take-off are subject to concerns over safety and air traffic controller workload.
4. Fleet Mix	Unknown (potentially large)	Unknown (potentially large costs)	Severe difficulty: National regulation of the type of aircraft used by air carriers is needed. This is contrary to Federal deregulation policies and could have serious economic consequences.
5. Capacity Control	Small	Unknown	Severe difficulty: National regulation of the routes and capacities is needed. Disruption of schedules would not be warranted by minimal emission benefits.
6. Airport Design Configurations	Small	Unknown	Large difficulty: Completely new airport designs are rare. Designs which reduce aircraft and motor vehicle operating times and densities are hard to put in regulation. Special pathways for towing tractors could be incorporated.

(1) Based on judgements of this author. Quantitative data not available.

APPENDIX SECTION A.11

TEST OF HYPOTHESIS H-11

Hypothesis H-11: "Techniques for implementation of national plus local controls are not adequate".

Issues: Aviation emission controls on a local option basis have been proposed but never implemented. As indicated in the Clean Air Act (Section 231), any aviation regulation shall take effect only after a period needed to permit development of the requisite technology. The availability of this technology is the subject of this hypothesis.

Discussion: Aviation emission controls as needed on a local basis could take several forms. The towing of aircraft between terminal gates and runways has been considered. Another option appears to be reduced aircraft engine operation during taxi-out or taxi-in procedures. Also, the back-log of aircraft waiting to take-off, sometimes ten or more could theoretically be eliminated by holding them at the gates until ready. Airport design considerations which reduce aircraft and motor vehicle congestion could also reduce air pollution emission densities. While all of these concepts to reduce or disperse emissions are theoretically possible, none have been routinely put into practice.

Data Evaluation: Demonstration studies were found only for aircraft towing, reduced engine operation and gate hold procedures. Five reference sources are evaluated in Table A-10 with the best and most recent references listed first. Since essentially all the studies support a "true" hypothesis outcome, a summary listing is not shown.

Reference 1 is by far the most extensive of the four references which deal with aircraft towing. It is still a "paper study", however. High speed tractors to tow the aircraft have been proposed by two manufacturers. Their use appears promising enough to warrant extensive testing at a major airport. A demonstration is therefore planned at the Seattle-Tacoma Airport in fiscal year 1982 (Reference 3 on Table A-10).

FAA sponsored two contracts to study potential nose gear problems due to high dynamic loadings from aircraft towing. One study found fatigue life of the nose gear was not affected while the other study predicted some problems could develop. Tug driver technique influences the potential damage and FAA concerns are still not resolved (Reference 2 on Table A-10).

The proposed Massachusetts Port Authority regulation to require aircraft towing was never promulgated after a study concluded towing could be hazardous and was ineffective for noise reduction (Reference 4 on Table A-10).

Reference 5 on Table A-10 describes a six week program to test reduced engine operating procedures and gate hold procedures. While safety problems were not experienced, the conclusion was made that additional development would be necessary to overcome air traffic controller workload difficulties (with gate hold procedures) and to more extensively demonstrate the feasibility of reduced engine taxi procedures.

Conclusions: Short-range aircraft towing has been conducted for years with no serious safety or operational problems. Long-range towing (ie. between the runway and the terminal gate) has never been practiced and would require further development of both equipment and operational procedures. Reduced aircraft engine operating procedures during taxi (especially taxi-in) and gate hold procedures appear possible but have been inadequately tested. These techniques are potentially useful but cannot be considered adequate until all safety and operational concerns can be resolved. Further development is required through extensive airport test and evaluation programs.

TABLE A-11
TEST OF HYPOTHESIS H-11

TECHNIQUES FOR NATIONAL PLUS LOCAL CONTROLS ARE NOT ADEQUATE

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
1.	Peat, Marwick, Mitchell & Co. (1980)	A. *Summary of Conclusions:*	
	p. 9	Existing experience with extended (long distance) aircraft towing operations between runways and terminal gates is very limited. Based on short distance experience, towing operations appear satisfactory from the technical and safety standpoints. However, concerns still remain with extended towing and cannot be resolved through	
	p. 72	"paper studies". Real-world demonstrations are needed. The Honolulu International Airport and/or Seattle-Tacoma International Airport are the most suitable.	
	p. 5	B. [illegible] Towing Experience: 1. Roissy-Charles De Gaulle Airport, Paris: Extended towing was initiated between the maintenance area and the terminal gates (approximately 5 miles). While problems were not experienced on B-747 or B-707 aircraft at low speeds, a yaw phenomenon of 2-3 feet was experienced above 20 mph with this procedure. Redesigned tow tractors were recommended.	
	p. 7	2. Boston-Logan International Airport: In 1976, the Massachusetts Port Authority proposed a regulation requiring aircraft towing in order to reduce noise impacts on nearby residents. Some testing was conducted ((see Reference 4 in this table)). The regulation is not yet implemented due to the following concerns: a. Damage to the aircraft nose gear structural integrity. b. Possible ramp and taxiway congestion. c. Undefined safety responsibility between the aircraft pilot and tractor driver. d. Competitive edge since only some airline carriers are affected ((assumes objectionable slow towing speeds)). e. Possible added equipment and crew costs by the affected airline carriers. f. *Extra air traffic controller workload.*	

Footnote:
*Comments by this author or conclusions not part of the reference cited are indicated by: ((.....)).

TABLE A-11 (CONT'D.)

TEST OF HYPOTHESIS H-11

TECHNIQUES FOR NATIONAL PLUS LOCAL CONTROLS ARE NOT ADEQUATE

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
1.(Cont'd)	Peat, Marwick, Mitchell & Co. (1980) p. 9	3. *Limited towing at other airports:*	Aircraft of two airlines are towed short distances at Los Angeles Airport because of engine blast problems. One airline is towing aircraft 6,300 feet between the hangers and terminal and reports a $150,000 per year fuel savings. Aircraft at San Francisco International Airport are towed between maintenance areas to terminal gates. No special problems in the above towing operations have *been reported.*
	pp. 12-18	C. <u>Towing Equipment and Procedures</u>: Currently available tractors are designed for short distance, low speed operation. Aircraft push-back operations (away from terminal gates) are normally at 2-3 mph. *Maximum* speeds with loaded aircraft are typically 8-10 mph. Since aircraft are now taxied at 20-30 mph, towing with available tractors would result in longer aircraft ground times, additional crew costs, and customer dissatisfaction with the service. These	
	p. 23	tractors *also use* tow bars attached to the aircraft nose wheel which could conceivably reduce the fatigue life of the nose gear.	
	pp. 14-18	High speed towing equipment has been <u>proposed</u> by Secmafer of France and Vanley Systems of Renton, Washington. Both tractors are designed for towing at 30-35 mph. The Secmafer System lifts the nose gear off the ground to hopefully prevent fatigue problems. The Vanley System features controls which can be transfered to the pilot and a radar collision avoidance system.	
	p. 23	D. <u>Operational Concerns with Towing</u>: The following conditions should exist in order to minimize airfield congestion or extra workload by air traffic controllers or pilots: 1. Adequate space near runways to connect tractors to arrival aircraft. 2. Adequate space to disconnect departure aircraft and allow aircraft engines to reach thermal stability. 3. Separate return roadways for tractors. 4. Few active runway crossings by towed aircraft. 5. Infrequent icy or high crosswind conditions which reduce controllability of towed aircraft.	

TABLE A-11 (CONT'D.)

TEST OF HYPOTHESIS H-11

TECHNIQUES FOR NATIONAL PLUS LOCAL CONTROLS ARE NOT ADEQUATE

REVERSE CHRONOLOGICAL ORDER	REFERENCE	TRUE	FALSE
1.(Cont'd)	Peat, Marwick, Mitchell & Co. (1980) p. 68	Operational conditions at 20 major airports were reviewed to determine their suitability for aircraft towing. The airports where initial demonstration projects would be easiest (emphasis was placed on airports where new roadways or staging areas or a large number of additional tow tractors could be avoided) were determined to be Honolulu and Seattle-Tacoma.	
2.	Aviation Week November (1980) p. 94	The Federal Aviation Administration (FAA) contracted Lockheed Aircraft and McDonnell Douglas Aircraft to study potential nose gear problems from towing aircraft. While the studies generally found the fatigue life was not affected, deviations from acceptable tug driver technique could cause high dynamic loadings. FAA concludes there are still safety and operational issues to be resolved.	
3.	Aviation Week October (1980) p. 39	The U.S. Department of Energy is planning a demonstration project of aircraft towing at Seattle-Tacoma Airport in fiscal year 1982.	
	p. 39	Air France has ordered four high-speed Secmafer aircraft tractors for testing at the Roissy-Charles DeGaulle Airport, Paris.	
4.	FAA (1977) p. VI-1	This was a "paper study" to analyze the impact of the proposed Massachusetts Port Authority requirement for aircraft towing at Boston-Logan International Airport. Conclusions are as follows: 1. The proposed towing is hazardous when compared to the alternative of normal taxiing. 2. Potential problems are in communications between pilot and tractor driver, airport congestion, jet blast to ground personnel, and aircraft passengers standing in the aisles. 3. Noise and cost benefits were not quantified due to inadequate data.	
	p. V-10	4. Aircraft emission reductions attributable to towing are 43% for THC and 53% for CO. This amounts to 11% and 13% of total airport emissions respectively.	
5.	Sampson (1974)	This reference describes a trial program in November and December 1973 to investigate the feasibility of reducing aircraft emissions by modifying aircraft ground operation procedures at the Hartsfield Atlanta International Airport.	
	p. 3	It was a cooperative effort by the U.S. EPA, FAA, and the Air Transportation Association. Aircraft were taxied with reduced engine operation (eg. operating 2 engines above idle rather than 3 engines at idle) for two weeks. This trial procedure was then combined with a gate hold procedure to minimize queuing times on the taxiways.	
	p. 12	While no operational or safety problems were experienced, the gate hold procedure added to the air traffic controller workload and the reduced engine operation procedure requires	

APPENDIX B - EMISSION COMPARISONS
(DESCRIBED IN CHAPTERS VIII AND IX)

TABLE B-1
AIRPORT/COUNTY EMISSION DENSITY RATIO
-NO CONTROLS

$(\frac{TONS}{KM^2}$ AIRPORT ÷ $\frac{TONS}{KM^2}$ COUNTY)

ID	CITY (AIRPORT)	1975 THC	1975 CO	1975 NO_x	1995 THC	1995 CO	1995 NO_x
ATL	ATLANTA	5.1	5.2	8.9	3.9	13.9	19.5
BOS	BOSTON	5.4	4.4	6.3	5.8	20.6	14.4
CLE	CLEVELAND	1.0	1.2	0.8	0.7	3.3	3.8
DCA	WASHINGTON(NATIONAL)	1.2	1.3	3.0	1.1	3.8	4.7
DEN	DENVER	0.4	0.3	0.5	0.3	0.7	0.9
DFW	DALLAS/FORT WORTH	0.8	1.0	1.4	0.7	2.4	2.5
DTW	DETROIT	0.4	0.3	0.5	0.3	0.9	0.9
EWR	NEWARK	1.1	0.7	1.1	1.1	3.1	2.6
HNL	HONOLULU	4.4	2.6	2.8	4.0	10.7	4.1
IAH	HOUSTON	0.6	1.2	0.8	0.5	2.2	1.5
JFK	NEW YORK(J.F. KENNEDY)	1.1	0.5	0.3	0.5	1.2	0.4
LAS	LAS VEGAS						
LAX	LOS ANGELES	6.8	4.4	7.1	4.7	13.5	9.7
LGA	NEW YORK(LA GUARDIA)	1.0	1.0	1.1	1.1	3.2	1.4
MCI	KANSAS CITY						
MEM	MEMPHIS	0.9	2.1	1.3	1.7	9.0	2.8
MIA	MIAMI						
MSP	MINNEAPOLIS	0.9	1.0	2.0	1.0	2.3	3.9
ORD	CHICAGO(O'HARE)	1.5	1.7	1.5	0.9	3.2	2.4
PHL	PHILADELPHIA	0.4	0.3	0.4	0.3	0.6	0.6
PHX	PHOENIX						
PIT	PITTSBURGH	0.4	0.3	0.3	0.6	1.3	0.8
SEA	SEATTLE-TACOMA						
SFO	SAN FRANCISCO	3.9	1.8	4.7	2.8	4.0	6.7
STL	ST. LOUIS	0.2	0.1	0.2	0.4	0.4	0.7
TPA	TAMPA						

TABLE B-2
AIRCRAFT THC ENGINE EMISSIONS
-WITHOUT ENGINE CONTROLS
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA	3227	2450	1909	2187	2468
BOS	BOSTON	1737	1807	1558	1707	1788
CLE	CLEVELAND	734	623	443	425	494
DCA	WASHINGTON(NATIONAL)	518	547	516	511	523
DEN	DENVER	1185	908	766	859	962
DFW	DALLAS/FORT WORTH	2068	1747	1683	1695	2030
DTW	DETROIT	1229	1071	996	1000	1020
EWR	NEWARK	1553	1231	1143	1241	1504
HNL	HONOLULU	2357	2147	2152	2271	2360
IAH	HOUSTON	946	1018	803	816	974
JFK	NEW YORK(J.F. KENNEDY)	9571	6441	5276	4571	4399
LAS	LAS VEGAS	1252	1157	974	1041	1299
LAX	LOS ANGELES	5512	4931	4004	3910	3801
LGA	NEW YORK(LA GUARDIA)	1005	1187	1135	1188	1291
MCI	KANSAS CITY	629	601	626	823	1035
MEM	MEMPHIS	373	462	594	732	895
MIA	MIAMI	2246	2211	2092	2412	2676
MSP	MINNEAPOLIS	562	648	583	668	779
ORD	CHICAGO(O'HARE)	8131	6646	5378	5463	5723
PHL	PHILADELPHIA	1645	1142	1149	1173	1310
PHX	PHOENIX	1494	988	868	786	955
PIT	PITTSBURGH	751	554	639	786	965
SEA	SEATTLE-TACOMA	951	933	716	725	774
SFO	SAN FRANCISCO	3623	2900	2226	2237	2338
STL	ST. LOUIS	1059	1103	1293	1576	2012
TPA	TAMPA	725	928	887	1025	1221
TOTALS		55083	46381	40409	41828	45596

TABLE B-3
AIRCRAFT THC ENGINE EMISSIONS
-EPA CONTROLS PROPOSED IN 1978
(ASSUMED FULLY IMPLEMENTED BY 1990)
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA				355	339
BOS	BOSTON				170	174
CLE	CLEVELAND				98	111
DCA	WASHINGTON(NATIONAL)				143	147
DEN	DENVER				195	208
DFW	DALLAS/FORT WORTH				210	222
DTW	DETROIT				130	133
EWR	NEWARK				203	235
HNL	HONOLULU				245	269
IAH	HOUSTON				205	203
JFK	NEW YORK(J.F. KENNEDY)				246	258
LAS	LAS VEGAS				165	184
LAX	LOS ANGELES				330	337
LGA	NEW YORK(LA GUARDIA)				156	162
MCI	KANSAS CITY				113	137
MEM	MEMPHIS				165	195
MIA	MIAMI				241	283
MSP	MINNEAPOLIS				151	178
ORD	CHICAGO(O'HARE)				478	505
PHL	PHILADELPHIA				307	314
PHX	PHOENIX				226	262
PIT	PITTSBURGH				190	228
SEA	SEATTLE-TACOMA				117	141
SFO	SAN FRANCISCO				200	211
STL	ST. LOUIS				135	154
TPA	TAMPA				121	141
TOTALS		Same as "NO CONTROLS"			5295	5731

TABLE B-4
AIRCRAFT THC ENGINE EMISSIONS
-ICAO CONTROLS OR LESS
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA			282	310	290
BOS	BOSTON			208	195	206
CLE	CLEVELAND			78	87	99
DCA	WASHINGTON(NATIONAL)			129	133	138
DEN	DENVER			158	178	190
DFW	DALLAS/FORT WORTH			190	233	257
DTW	DETROIT			114	128	131
EWR	NEWARK			186	228	267
HNL	HONOLULU			196	218	238
IAH	HOUSTON			150	191	189
JFK	NEW YORK(J.F. KENNEDY)			310	311	337
LAS	LAS VEGAS			153	180	206
LAX	LOS ANGELES			352	376	390
LGA	NEW YORK(LA GUARDIA)			177	183	195
MCI	KANSAS CITY			99	126	160
MEM	MEMPHIS			147	178	215
MIA	MIAMI			244	292	348
MSP	MINNEAPOLIS			116	138	160
ORD	CHICAGO(O'HARE)			458	492	527
PHL	PHILADELPHIA			293	319	331
PHX	PHOENIX			292	237	278
PIT	PITTSBURGH			154	188	229
SEA	SEATTLE-TACOMA			90	110	133
SFO	SAN FRANCISCO			219	234	255
STL	ST. LOUIS			147	184	228
TPA	TAMPA			115	139	165
TOTALS		Same as "NO CONTROLS"		5057	5588	6162

TABLE B-5
AIRCRAFT THC ENGINE EMISSIONS
-ICAO (JUST MEETS STANDARDS)
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA			1263	1614	1953
BOS	BOSTON			488	592	723
CLE	CLEVELAND			223	290	366
DCA	WASHINGTON(NATIONAL)			340	389	447
DEN	DENVER			486	600	719
DFW	DALLAS/FORT WORTH			540	723	902
DTW	DETROIT			332	424	530
EWR	NEWARK			390	510	642
HNL	HONOLULU			805	951	1146
IAH	HOUSTON			420	573	704
JFK	NEW YORK(J.F. KENNEDY)			1118	1179	1360
LAS	LAS VEGAS			351	455	563
LAX	LOS ANGELES			1115	1314	1470
LGA	NEW YORK(LA GUARDIA)			489	532	613
MCI	KANSAS CITY			267	364	481
MEM	MEMPHIS			258	320	395
MIA	MIAMI			598	757	952
MSP	MINNEAPOLIS			346	434	540
ORD	CHICAGO(O'HARE)			1928	2284	2660
PHL	PHILADELPHIA			499	603	681
PHX	PHOENIX			434	429	524
PIT	PITTSBURGH			322	414	527
SEA	SEATTLE-TACOMA			282	362	459
SFO	SAN FRANCISCO			615	729	850
STL	ST. LOUIS			318	437	577
TPA	TAMPA			336	436	550
TOTALS		Same as "NO CONTROLS"		14563	17715	21334

TABLE B-6
AIRCRAFT NO_x ENGINE EMISSIONS
-WITHOUT ENGINE CONTROLS
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA	2336	3359	4760	5928	7366
BOS	BOSTON	1016	1408	1975	2608	3248
CLE	CLEVELAND	620	797	1128	1459	1850
DCA	WASHINGTON(NATIONAL)	892	1141	1427	1634	1895
DEN	DENVER	1060	1440	1950	2395	2924
DFW	DALLAS/FORT WORTH	1562	2001	2697	3490	4451
DTW	DETROIT	903	1191	1624	2057	2637
EWR	NEWARK	662	841	1174	1532	1925
HNL	HONOLULU	1017	1335	1695	2004	2432
IAH	HOUSTON	687	962	1366	1784	2366
JFK	NEW YORK(J.F. KENNEDY)	2346	2299	2749	2800	3169
LAS	LAS VEGAS	549	744	1046	1339	1692
LAX	LOS ANGELES	2555	3180	3891	4531	5061
LGA	NEW YORK(LA GUARDIA)	1234	1399	1470	1571	1806
MCI	KANSAS CITY	508	698	1034	1374	1801
MEM	MEMPHIS	476	613	857	1057	1303
MIA	MIAMI	1514	1992	2632	3257	4066
MSP	MINNEAPOLIS	806	1286	1471	1832	2289
ORD	CHICAGO(O'HARE)	3678	4613	5775	6717	7671
PHL	PHILADELPHIA	842	897	1296	1660	1947
PHX	PHOENIX	481	632	831	1037	1299
PIT	PITTSBURGH	760	985	1501	1927	2468
SEA	SEATTLE-TACOMA	811	1039	1368	1718	2144
SFO	SAN FRANCISCO	1656	1958	2394	2830	3293
STL	ST. LOUIS	781	1075	1712	2327	3131
TPA	TAMPA	632	968	1274	1624	2032
TOTALS		30384	38853	51099	62492	76286

TABLE B-7
AIRCRAFT NO_x ENGINE EMISSIONS
-EPA CONTROLS PROPOSED IN 1978
(ASSUMED FULLY IMPLEMENTED BY 1990)
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA				3834	4400
BOS	BOSTON				1691	1909
CLE	CLEVELAND				927	1063
DCA	WASHINGTON(NATIONAL)				1135	1187
DEN	DENVER				1601	1799
DFW	DALLAS/FORT WORTH				2327	2710
DTW	DETROIT				1309	1489
EWR	NEWARK				970	1127
HNL	HONOLULU				1182	1350
IAH	HOUSTON				1198	1425
JFK	NEW YORK(J.F. KENNEDY)				1712	1772
LAS	LAS VEGAS				857	1002
LAX	LOS ANGELES				2771	2868
LGA	NEW YORK(LA GUARDIA)				1072	1124
MCI	KANSAS CITY				952	1122
MEM	MEMPHIS				773	882
MIA	MIAMI				2045	2336
MSP	MINNEAPOLIS				1073	1242
ORD	CHICAGO(O'HARE)				4170	4400
PHL	PHILADELPHIA				1096	1163
PHX	PHOENIX				735	859
PIT	PITTSBURGH				1290	1506
SEA	SEATTLE-TACOMA				1029	1166
SFO	SAN FRANCISCO				1777	1879
STL	ST. LOUIS				1524	1854
TPA	TAMPA				1042	1194
TOTALS		Same as "NO CONTROLS"			40092	44828

TABLE B-8
AIRCRAFT NO_x ENGINE EMISSIONS
-ICAO CONTROLS (OR LESS)
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA			4959	6404	8076
BOS	BOSTON			2163	2928	3706
CLE	CLEVELAND			1163	1553	2024
DCA	WASHINGTON(NATIONAL)			1453	1752	2089
DEN	DENVER			2088	2668	3314
DFW	DALLAS/FORT WORTH			2794	3763	4895
DTW	DETROIT			1742	2251	2921
EWR	NEWARK			1250	1621	2127
HNL	HONOLULU			2010	2375	2862
IAH	HOUSTON			1425	1917	2547
JFK	NEW YORK(J.F. KENNEDY)			3196	3255	3665
LAS	LAS VEGAS			1167	1532	1980
LAX	LOS ANGELES			4387	5121	5728
LGA	NEW YORK(LA GUARDIA)			1490	1663	1962
MCI	KANSAS CITY			999	1409	1905
MEM	MEMPHIS			893	1160	1483
MIA	MIAMI			2798	3528	4442
MSP	MINNEAPOLIS			1399	1812	2296
ORD	CHICAGO(O'HARE)			6141	7197	8428
PHL	PHILADELPHIA			1372	1799	2173
PHX	PHOENIX			877	1128	1435
PIT	PITTSBURGH			1654	2234	2940
SEA	SEATTLE-TACOMA			1373	1730	2179
SFO	SAN FRANCISCO			2644	3136	3654
STL	ST. LOUIS			1788	2556	3485
TPA	TAMPA			1262	1641	2085
TOTALS		Same as "NO CONTROLS"		54487	67133	84401

TABLE B-9
AIRCRAFT CO ENGINE EMISSIONS
-WITHOUT CONTROLS
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA	7177	5382	6084	6920	7787
BOS	BOSTON	3420	4078	4667	5206	5255
CLE	CLEVELAND	1910	2076	2287	2593	3012
DCA	WASHINGTON(NATIONAL)	1921	2362	2467	2540	2636
DEN	DENVER	3143	3315	3674	4167	4282
DFW	DALLAS/FORT WORTH	3260	3427	3925	4433	5046
DTW	DETROIT	2331	2501	2868	3179	3390
EWR	NEWARK	2176	2085	2360	2750	3281
HNL	HONOLULU	4923	6036	7255	8257	9127
IAH	HOUSTON	1723	2149	2472	2919	3256
JFK	NEW YORK(J.F. KENNEDY)	11980	9461	9308	8833	9177
LAS	LAS VEGAS	3966	5249	6538	7792	9190
LAX	LOS ANGELES	7701	7939	7887	8292	8541
LGA	NEW YORK(LA GUARDIA)	2925	3286	3033	3107	3285
MCI	KANSAS CITY	1513	1750	2145	2684	3254
MEM	MEMPHIS	3263	3531	4670	5656	6834
MIA	MIAMI	6327	6810	8702	10628	12748
MSP	MINNEAPOLIS	1870	2533	2766	3265	3859
ORD	CHICAGO(O'HARE)	11806	11787	[illegible]048	13085	14093
PHL	PHILADELPHIA	2835	2566	2916	2754	2964
PHX	PHOENIX	4023	3971	4466	4954	5825
PIT	PITTSBURGH	1498	1498	1883	2303	2773
SEA	SEATTLE-TACOMA	1999	2470	2865	3386	4043
SFO	SAN FRANCISCO	5225	5060	4809	5102	5450
STL	ST. LOUIS	2574	2719	3126	3556	4130
TPA	TAMPA	2211	2718	3254	3849	4558
TOTALS		103700	106759	118475	132210	147796

TABLE B-10
AIRCRAFT CO ENGINE EMISSIONS
-EPA CONTROLS PROPOSED IN 1978
(ASSUMED FULLY IMPLEMENTED BY 1990)
(METRIC TONS PER YEAR)

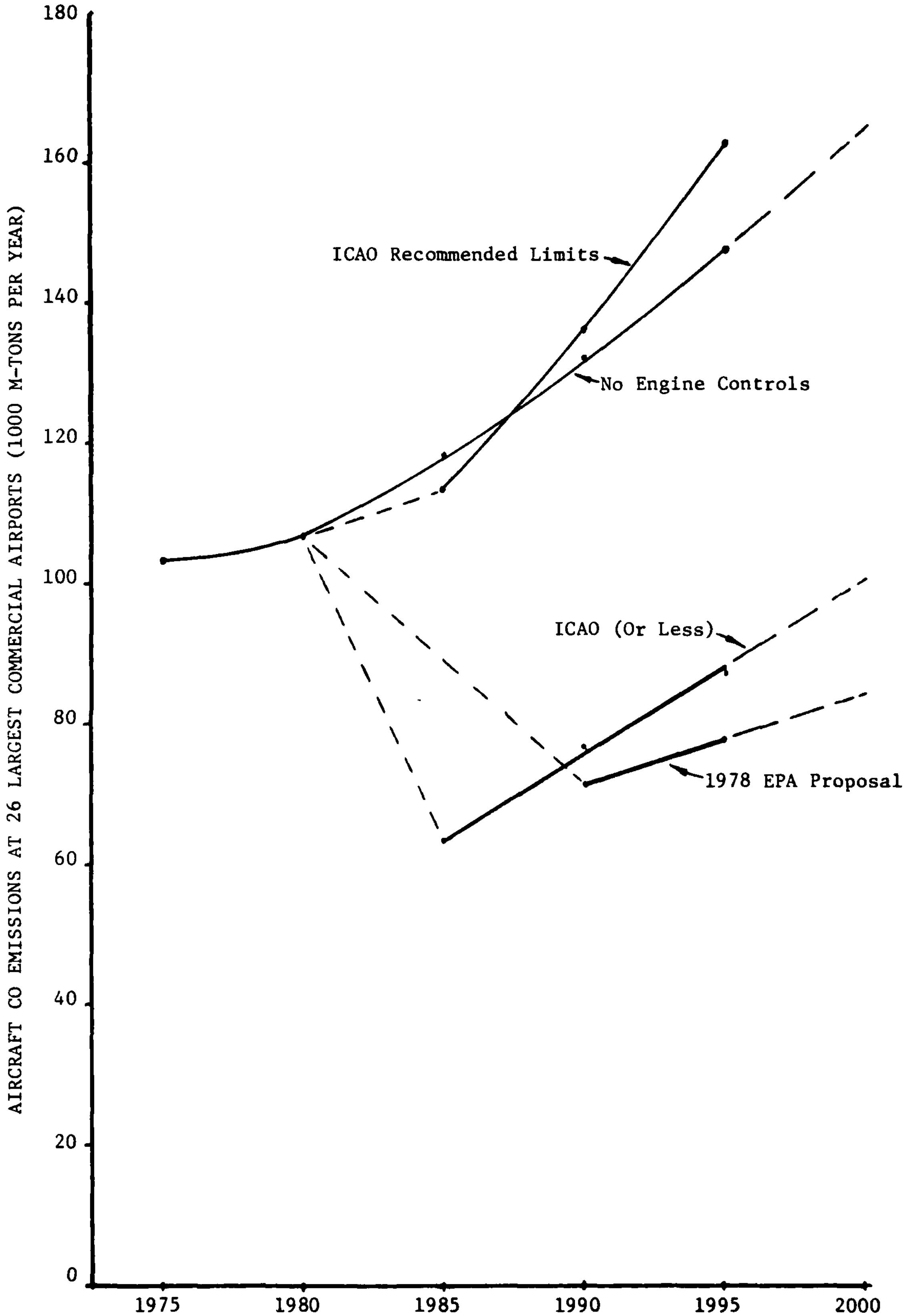
ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA				2888	3072
BOS	BOSTON				2881	2669
CLE	CLEVELAND				1824	2095
DCA	WASHINGTON(NATIONAL)				1729	1792
DEN	DENVER				2734	2641
DFW	DALLAS/FORT WORTH				1950	2065
DTW	DETROIT				1669	1666
EWR	NEWARK				1102	1287
HNL	HONOLULU				4423	4830
IAH	HOUSTON				1611	1616
JFK	NEW YORK(J.F. KENNEDY)				2293	2435
LAS	LAS VEGAS				6362	7392
LAX	LOS ANGELES				2731	2815
LGA	NEW YORK(LA GUARDIA)				1511	1567
MCI	KANSAS CITY				1534	1852
MEM	MEMPHIS				4803	5800
MIA	MIAMI				7391	9056
MSP	MINNEAPOLIS				2011	2372
ORD	CHICAGO(O'HARE)				4094	4400
PHL	PHILADELPHIA				1274	1288
PHX	PHOENIX				4056	4740
PIT	PITTSBURGH				1231	1459
SEA	SEATTLE-TACOMA				2180	2682
SFO	SAN FRANCISCO				1971	2079
STL	ST. LOUIS				1575	1592
TPA	TAMPA				2347	2793
TOTALS		Same as "NO CONTROLS"			70175	78055

TABLE B-11
AIRCRAFT CO ENGINE EMISSIONS
-ICAO CONTROLS (OR LESS)
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA			3016	3738	4559
BOS	BOSTON			2803	3152	3158
CLE	CLEVELAND			1598	1894	2253
DCA	WASHINGTON(NATIONAL)			1707	1869	2066
DEN	DENVER			2450	2842	2932
DFW	DALLAS/FORT WORTH			1776	2329	2798
DTW	DETROIT			1517	1753	1845
EWR	NEWARK			1008	1275	1605
HNL	HONOLULU			3584	4207	4665
IAH	HOUSTON			1284	1739	1921
JFK	NEW YORK(J.F. KENNEDY)			2284	2347	2599
LAS	LAS VEGAS			5307	6446	7564
LAX	LOS ANGELES			2588	2874	3143
LGA	NEW YORK(LA GUARDIA)			1614	1784	2033
MCI	KANSAS CITY			1351	1782	2339
MEM	MEMPHIS			4027	4915	5995
MIA	MIAMI			6121	7739	9656
MSP	MINNEAPOLIS			1740	2131	2628
ORD	CHICAGO(O'HARE)			3823	4380	5160
PHL	PHILADELPHIA			1657	1441	1585
PHX	PHOENIX			3670	4155	4935
PIT	PITTSBURGH			1037	1329	1685
SEA	SEATTLE-TACOMA			1780	2267	2874
SFO	SAN FRANCISCO			1896	2123	2409
STL	ST. LOUIS			1628	1913	2213
TPA	TAMPA			2079	2595	3239
TOTALS		Same as "NO CONTROLS"		63345	75019	87819

TABLE B-12
AIRCRAFT CO ENGINE EMISSIONS
-ICAO (JUST MEETS STANDARDS)
(METRIC TONS PER YEAR)

ID	CITY (AIRPORT)	1975	1980	1985	1990	1995
ATL	ATLANTA			7538	9580	11771
BOS	BOSTON			4268	5166	5692
CLE	CLEVELAND			2319	2878	3526
DCA	WASHINGTON(NATIONAL)			2722	3057	3451
DEN	DENVER			4072	4875	5398
DFW	DALLAS/FORT WORTH			3568	4752	5873
DTW	DETROIT			2647	3260	3845
EWR	NEWARK			2096	2751	3498
HNL	HONOLULU			6816	8049	9348
IAH	HOUSTON			2605	3543	4283
JFK	NEW YORK(J.F. KENNEDY)			6841	7176	8211
LAS	LAS VEGAS			6358	7882	9399
LAX	LOS ANGELES			6750	7903	8811
LGA	NEW YORK(LA GUARDIA)			3197	3492	3978
MCI	KANSAS CITY			2172	2890	3760
MEM	MEMPHIS			4604	5646	6904
MIA	MIAMI			8063	10214	12766
MSP	MINNEAPOLIS			2890	3584	4428
ORD	CHICAGO(O'HARE)			11534	13624	15857
PHL	PHILADELPHIA			2729	2874	3299
PHX	PHOENIX			4401	5125	6143
PIT	PITTSBURGH			1892	2460	3144
SEA	SEATTLE-TACOMA			2764	3527	4460
SFO	SAN FRANCISCO			4075	4778	5519
STL	ST. LOUIS			2613	3283	4040
TPA	TAMPA			3219	4065	5062
TOTALS		Same as "NO CONTROLS"		112753	136434	162466



PROJECTION OF AIRCRAFT ENGINE CARBON MONOXIDE EMISSIONS
FIGURE B-1

APPENDIX C - EVENT TREE DEVELOPMENT

CALCULATIONS OF AIRCRAFT EMISSION (G) USED IN "EVENT TREE" APPLICATION (CHAPTER VIII-E)

1. Compute Emissions Per Average Aircraft Landing and Takeoff (LTO) Cycle:

-Los Angeles airport (LAX) is chosen for this example.

Assumed Aircraft (Engine) Fleet Mix		1980 LTOs[1] (%)	CO (2) (kg/LTO Cycle)	Weighted CO Emissions
B727-200	(3JT8D-17)	50697 (28%)	25	7.0
DC10-30	(3CF6-6D)	24708 (14%)	53	7.4
B707-320B	(4JT-3D-7)	36486 (20%)	119	23.8
B747	(4JT-9D-7)	16971 (09%)	118	10.6
DC9/B737	(2JT-8D-17)	40942 (23%)	17	3.9
L1011	(3RR-RB211-22B)	11088 (06%)	90	5.4
		180892 (100%)		

Total Emissions (kg/"average LTO")................. $\boxed{58.}$

2. Compute "Worst Hour" Emissions:

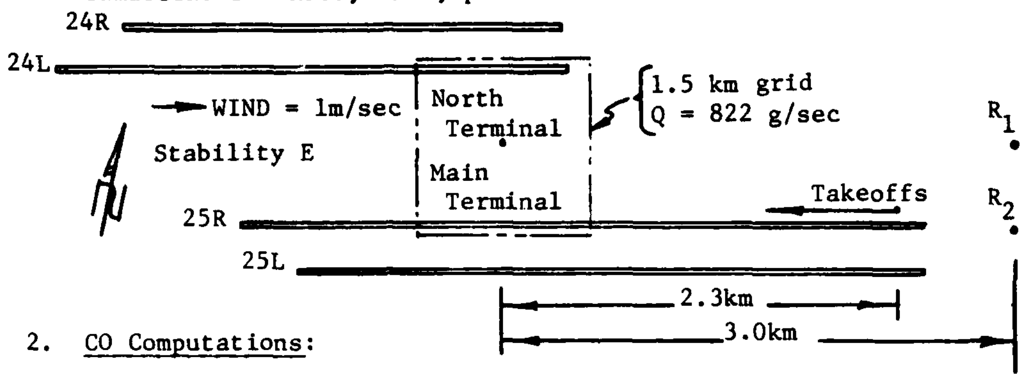
-51 takeoffs per hour are considered a reasonable maximum and occurred during the 8-9 a.m. period on August 4, 1977 at LAX (Yamartino, 1979). Also assume 51 complete LTO cycles per hour (probably worse than expected).

$$\text{-CO:}\quad \frac{51\text{ LTOs}}{\text{Hr}} \times \frac{58\text{ kg CO}}{\text{LTO}} \times \frac{1000\text{ g/kg}}{3600\text{ Sec/Hr}} = \underline{\underline{822\text{ g CO/Sec}}}$$

(1) U.S. EPA (January 1977), AC 77-01, page 48 -- specific for LAX.
(2) U.S. EPA (February 1980), AP 42, Supplement 10, page 3.2.1-14 (All CO emissions assumed in taxi/idle mode).

CALCULATION OF DISPERSION FACTOR (A) USED IN "EVENT TREE" APPLICATION (CHAPTER VIII-E)

1. A simple geometry of the LAX airport is assumed. It is reasonably close to that presented in a more complex model by Yamartino and Rote, 1979, p. 131.



2. CO Computations:

-Assume: (1) The "worst case" wind and stability shown above.
(2) All CO emissions are uniformly distributed in the 1.5 km grid area above (tendency to under-estimate).
(3) Curves in Turner (1970, page 8) are reasonable for an hourly concentration estimate (tendency to over-estimate).
(4) "Virtual source" method for areas. Since this tends to over-estimate at receptor R_1, the average of the R_1 and R_2 (edge of grid) estimates is used.

-Compute: The initial horizontal standard deviation (σ_{yo}) for the grid is: $\frac{1.5 \text{ km}}{4.3} = 0.35$ km. (Turner, 1970, p. 40)

The virtual distance (x_y) is therefore = 8.5 km. (Turner, 1970, p. 8)

Then for $x + x_y = 3.0 + 8.5 = 11.5$ km, (Turner, 1970, p. 40)

...$\sigma_y = 470$ meters; $\sigma_z = 42$ m (Turner, 1970, p. 8)

Assuming the effective plume height (H) is 10 meters:

The center line concentration at R_1 $(\chi_1) = \frac{Q}{\pi \sigma_y \sigma_z u} \exp[-1/2 \; (\frac{H}{\sigma z})^2]$ (Turner, 1970, p. 6)

$$\chi_1 = \frac{822 \text{ g/sec CO}}{\pi(470\text{m})(42\text{m})(1\text{m/sec})} \exp\left[-1/2 \; (\frac{10}{42})^2\right] = 12.9\text{mg/m}^3$$

(Turner, 1970, p. 8)

The outer edge concentration at R_2 $(\chi_2) = 13.25 \frac{\text{mg}}{\text{m}^3} (0.972) \exp\left[-1/2 (\frac{y}{\sigma y})^2\right]$

where $y = 750$, $\sigma_y = 470$.

$\chi_2 = 3.61$

2. <u>CO Computations</u> (Cont'd.)

   Then averaging: (χ_1 and χ_2) $\bar{\chi}$ at R_2 = $\underline{\underline{8.26^{(1)}\ mg/m^3\ CO\ max\ hour}}$

3. Convert the CO concentration to a dispersion factor (A) for use in the "event trees":

$$A = \frac{\chi}{Q} = \frac{8260\ \mu g/m^3\ CO}{822\ g\ CO/sec} = 10.8\ \left(\frac{\mu g/m^3}{g/sec}\right)$$

4. Event Tree computer runs are made with the assumptions shown in Figure VIII-7 and described below:

   -Assume the LAX emissions can be 20% greater than those predicted (25% of the time) and 20% less (25% of the time).

   -Assume CO aircraft engine controls of 50%, 60% or 70% can be implemented with equal probabilities (0.33 each).

   -Assume the "worst hourly" dispersion modelling errors can range from factors of 3 too low to factors of 3 too high (with probabilities shown in Figure VIII-7).

5. The resulting event tree results from the above calculations are graphed and shown in Figure VIII-8.

(1) Note that this predicted concentration is about a factor of <u>3 higher</u> than Yamartino and Rote, 1979.

```
/******************   EVENT  TREE   ***********************************/
EVENT: PROCEDURE OPTIONS (MAIN);
   DCL (G(3), PG(3),/* GENERATED EMISSIONS,  PROBABILITY OF G  */
        E(3),PE(3), /* EMISSION CONTROLS, PROB. OF E  */
        A(5),PA(5), /* AIR DISPERSION COEF. , PROB. OF A  */
        U(5),PU(5), /* UNCERTAINTY OF PREDICTION, PROB. OF U  */
        C(225),      /* COMPUTED CONCENTRATION ARRAY  */
        P(225),      /* PROBABILITY  ARRAY  */
        SP(225),     /* SUM OF PROB. ARRAY  */
        MAXVAL,TEMP,SAVE,SUM)  FLOAT DEC;          /* TEMP VALUES */
   DCL (I,J,K,L,      /* INDEX OF G,E,A,U  */
        ID,           /* ID NUMBER OF ARRAYS (1 TO 375)  */
        M,N,          /* SORT ROUTINE COUNTERS  */
        MAX_POS)      /* POSITION OF MAX CONCENTRATION IN ARRAY  */
           FIXED DECIMAL;
   GET LIST (G,E,A,U,PG,PE,PA,PU);

   /***  COMPUTE 225 CONCENTRATIONS AND PROBABILITIES   ***/
   DO I = 1 TO 3;
     DO J = 1 TO 3;
       DO K = 1 TO 5;
         DO L = 1 TO 5;
           ID = I + 3*(J-1) + 9*(K-1) + 45*(L-1); /* ID FOR ARRAYS */
           C(ID) = G(I) * E(J) * A(K) * U(L);
           P(ID) = PG(I)*PE(J) *PA(K) *PU(L);
           END;
         END;
       END;
     END;

   /***  SORT C(225) ARRAY FROM SMALL TO LARGE AND KEY TO PU(225) ***/
   DO M = 225 TO 2 BY -1;  /* REPEAT FOR LISTS OF DIMINISHING SIZE */
        MAXVAL = C(1);
        MAXPOS = 1 ;
        /**   SEARCH SUB_LIST FOR MAXVAL    **/
        DO N = 2 TO M ;
             IF C(N) > MAXVAL    THEN DO;
                  MAXVAL = C(N);
                  MAXPOS = N;
                  END;
             END;
        /**  SWAP TO PUT MAXVAL AT END OF LIST , ALSO SWAP PROB. **/
        TEMP = C(M);
        SAVE = P(M);
        C(M) = C(MAXPOS);
        P(M) = P(MAXPOS);
        C(MAXPOS) = TEMP;
        P(MAXPOS) = SAVE;
        END;
```

```
/***   FIND SUM OF PROBABILITIES   ***/
SUM = 0.0 ;
DO M = 1 TO 225 ;
     SP(M) = SUM + P(M);
     SUM = SP(M);
     END;

 /***   PRINT INPUT DATA   ***/
     PUT SKIP(1) EDIT('GENERATED','EMISSION','AIR  COEF.',
                      'UNCERTAINTY')
                (X(10),A(9),X(11),A(8),X(12),A(10),X(10),A(11));
     PUT SKIP(1) EDIT('EMISSIONS','CONTROLS','DISPERSION',
                      'OF PREDICTION')
                (X(10),A(9),X(11),A(8),X(12),A(10),X(10),A(13));
     PUT SKIP(1) EDIT('(KILOGRAMS/SEC)','( FRACTION LEFT)',
                      '(1000*CONC*U/Q)','(FRACTION ADJUSTMENT)')
                      (COL(8),A,COL(28),A,COL(49),A,COL(67),A);
     PUT SKIP(1) LIST(REPEAT('_',119));
     DO I = 1 TO 3;
          PUT SKIP(1) EDIT(G(I),E(I),A(I),U(I))
            (COL(7),F(10,1),COL(32),F(5,3),COL(50),E(10,2),COL(74),
             F(5,3));
           END;
     DO I = 4 TO 5;
          PUT SKIP(1) EDIT(A(I))   (X(49),E(10,2));
          PUT SKIP(0) EDIT(U(I))  (COL(74),F(5,3));
          END;
     PUT SKIP(2) EDIT('PROBABILITIES OF ABOVE')  (X(6),A);
     PUT SKIP(1) LIST(REPEAT('_',119));
     DO I = 1 TO 3 ;
          PUT SKIP(1) EDIT(PG(I),PE(I),PA(I),PU(I)) (COL(10),F(5,2),
                    COL(32),F(5,2),COL(53),F(5,2),COL(74),F(5,2));
          END;
     DO I = 4 TO 5 ;
          PUT SKIP(1) EDIT(PA(I))(COL(53),F(5,2));
          PUT SKIP(0) EDIT(PU(I)) (COL(74),F(5,2));
          END;

     PUT SKIP(3) LIST(REPEAT('_',119));
/***   PRINT COMPUTED DATA   ***/
     PUT SKIP(3) LIST('CONCENTRATIONS (MICROGRAMS PER CUB METER):');
     PUT SKIP(1) LIST(C);
     PUT SKIP(3) LIST('PROBABILITY OF CONCENTRATIONS LESS THAN:');
     PUT SKIP(1) LIST(SP);
     PUT SKIP(3) LIST('PROBABILITIES: ');
     PUT SKIP(1) LIST(P);
END;   /*  MAIN PROGRAM  */
```

GENERATED EMISSIONS (KILOGRAMS/SEC)	EMISSION CONTROLS (FRACTION LEFT)	AIR COEF. DISPERSION (1000*CONC*U/Q)	UNCERTAINTY OF PREDICTION (FRACTION ADJUSTMENT)
658.0	0.300	1.08E+01	0.330
822.0	0.400	0.00E+00	0.500
986.0	0.500	0.00E+00	1.000
		0.00E+00	2.000
		0.00E+00	3.000

PROBABILITIES OF ABOVE

0.25	0.33	1.00	0.20
0.50	0.33	0.00	0.20
0.25	0.33	0.00	0.20
		0.00	0.20
		0.00	0.20

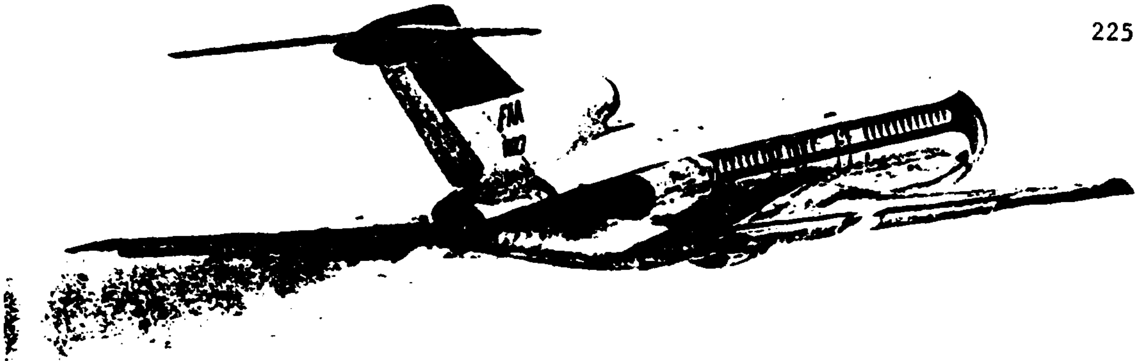
CONCENTRATIONS (MICROGRAMS PER CUB METER):

0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7.03533E+02	8.78882E+02	9.38044E+02	1.05423E+03	1.06595E+03
1.17184E+03	1.17255E+03	1.33163E+03	1.40564E+03	1.42127E+03
1.46480E+03	1.59731E+03	1.75705E+03	1.77551E+03	1.77659E+03
2.12975E+03	2.13191E+03	2.21939E+03	2.66219E+03	2.66327E+03
2.84255E+03	3.19463E+03	3.55103E+03	3.55319E+03	4.25951E+03
4.26383E+03	4.43879E+03	5.32439E+03	5.32655E+03	5.68511E+03
6.38927E+03	6.39575E+03	7.10207E+03	7.10639E+03	7.98983E+03
8.51903E+03	8.52767E+03	8.87759E+03	9.58391E+03	1.06487E+04
1.06531E+04	1.06595E+04	1.27785E+04	1.33163E+04	1.59731E+04

PROBABILITY OF CONCENTRATIONS LESS THAN:

0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.66499E-02	4.99499E-02	6.65999E-02	8.32499E-02	9.98999E-02
1.33199E-01	1.49849E-01	1.83149E-01	1.99799E-01	2.16449E-01
2.49749E-01	2.66399E-01	2.83049E-01	3.16349E-01	3.32999E-01
3.49649E-01	3.66299E-01	3.99599E-01	4.16249E-01	4.49549E-01
4.66199E-01	4.82849E-01	5.16149E-01	5.32799E-01	5.49449E-01
5.66099E-01	5.99399E-01	6.16049E-01	6.49349E-01	6.65999E-01
6.82649E-01	6.99299E-01	7.32599E-01	7.49249E-01	7.82549E-01
7.99199E-01	8.15849E-01	8.49149E-01	8.65799E-01	8.82449E-01
9.15749E-01	9.32399E-01	9.49049E-01	9.82349E-01	9.98999E-01

APPENDIX D - "AIRCRAFT AND AIR POLLUTION"
(JOURNAL PUBLICATION)



Aircraft and air pollution

The pollutants of greatest concern are hydrocarbons and NO_x; but a direct link between aircraft emissions and health or welfare effects has yet to be demonstrated

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Are federal regulations needed to control air pollution from aircraft?

The Clean Air Act directs the EPA administrator to issue emission standards for "aircraft engines which in his judgment cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare." Critics charge that the regulations, first issued in 1973, are overly complex and stringent, and that immediate energy shortages and domestic economic problems may take precedence over pollution remedies that take years or even decades to implement. Furthermore, they say, detailed air quality studies have yet to substantiate EPA's 1973 determination that aircraft directly endanger public health or welfare.

Proponents argue that ambient air standards for oxidants and other pollutants are frequently violated and will continue to be unless the best available control technology is applied to many sources—including those the size of airports.

Aircraft in perspective

Emissions from aircraft are a small part of total emissions from all sources on a national scale. Aircraft account for 1% of hydrocarbons (HC), oxides of nitrogen (NO_x), and carbon monoxide (CO) (*1*), and an even smaller fraction of particulate matter (PM) and oxides of sulfur (SO_x) (Figure 1). Small, general aviation aircraft are the least important of the three categories shown in the figure; they have recently been exempted from all emission standards (*2*). Commercial aircraft have lower HC but higher NO_x emissions than do military aircraft due to a greater proportion of larger and newer engines.

On the regional and local scales, where identifiable effects on health and welfare usually occur, the contributions of aircraft can be greater. The region considered in Figure 1 includes 10 Atlanta-area counties for area sources and a grid extending 12 miles from the Atlanta airport for point sources (*3*); aircraft contribute approximately 3% of the emissions in this region. The contribution could increase to 6–10% by 1990, however, as air traffic increases and air pollution controls are applied to other sources. Evaporative emissions from the storage and transfer of aircraft fuel are also projected to increase, by a factor of four. A switch to alternative fuels with lower vapor pressures, such as those derived fr[illegible] shale oil, could cut this increase.

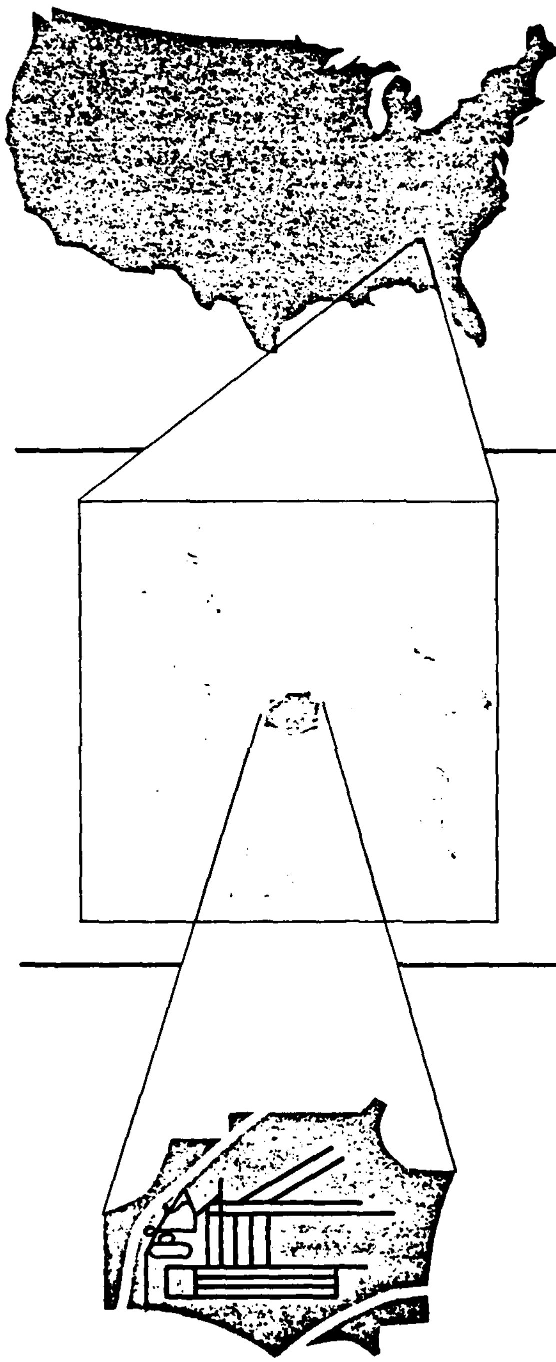
Aircraft are the dominant source within the Atlanta airport; proposed control strategies have generally focused on aircraft engine emission [illegible] ductions rather than other airp[illegible] sources. Emissions data as shown [illegible] Figure 1 are not always representat[illegible] of air quality effects, however. Aircr[illegible] emissions are distributed through[illegible] much of the airport and are subject [illegible] considerable atmospheric dilution[illegible] contrast, emissions from automo[illegible] traffic are often concentrated in c[illegible] gested terminal areas with redu[illegible] potential for atmospheric mixi[illegible] (Recent measurements of CO in[illegible] and outside of a congested airp[illegible] terminal area were less than levels [illegible] sociated with health effects, but [illegible] ther studies may be necessary (*4*)[illegible]

Emission studies such as those [illegible] sented in Figure 1 have other ser[illegible] shortcomings. National emissions [illegible] are subject to inaccuracies due to [illegible] large number of sources and calc[illegible] tions involved; this is especially tru[illegible] aircraft because the translation o[illegible] cent emission-factor data over [illegible] many operational modes and n[illegible] different airport situations can [illegible] complex task. Regional differenc[illegible] emissions are bound to occur. Th[illegible] contribution of the Atlanta airpo[illegible] regional emissions appears to be [illegible] in most regions, it is 1% or less ([illegible]

Another way to suggest the im[illegible] tance of aircraft as an air poll[illegible] source is by comparison with [illegible] source categories. Aircraft hydr[illegible] bon emissions are plotted in Fig[illegible] along with the top 60 source cate[illegible] for which EPA is considering [illegible]

0013-936X/81/0915-0391$01.25/0

FIGURE 1
Aircraft contribution: 1% nationwide



National

Source	*HC*	*NO_x*	*CO*
All aircraft	1.2%	0.6%	0.6%
Commercial	0.3	0.4	0.2
Military	0.7	0.2	0.2
General aviation	0.2	—	0.2
All sources	30 Mt/y	22 Mt/y	116 Mt/y

Regional (Atlanta area)

Source	HC	NO_x	CO
Aircraft	3.2%	3.1%	2.4%
Fuel evaporation	0.8	—	—
All sources	89 kt/y	75 kt/y	300 kt/y

Local (Atlanta airport)

Source	HC	NO_x	CO
Aircraft	69%	75%	58%
Fuel evaporation	11	—	—
Traffic, other	20	22	42
All sources	3.9 kt/y	2.9 kt/y	9.5 kt/y

Sources. EPA-450/4-79-019, EPA-450/3-75-052 tional New Source Performance Standards (NSPS) (*6*). The 27 sources for which NSPS have already been promulgated are not shown. Such comparisons are not frequently made since aircraft are regulated in a different part of the federal Clean Air Act and by different divisions within EPA. Aircraft rank as the 11th highest category, both when comparing annual emissions (T_a) and emissions reduction potential ($T_s - T_n$), the difference between levels with current control standards (T_s) and levels projected with new or hypothesized control standards (T_n). (Aircraft emissions between cities are not included—only those from aircraft landing and takeoff cycles in the airport vicinity. A 70% hydrocarbon control averaged over all aircraft is assumed.)

There are strong pressures for EPA to regulate all HC sources possible since the oxidant ambient air quality standard cannot be met until at least 1987 and then only with a 46% reduction in emissions from the 1977 level (*7*). This reduction requires strict vehicular emission control standards, automotive inspection and maintenance programs, and vigorous NSPS programs. The aircraft emission reduction potential represents 2% of the 46% needed nationwide. The number of stationary sources for which NSPS will ultimately be promulgated remains to be seen, but could include many or even most of the sources represented in Figure 2.

No direct effects

Nearly 200 technical reports and papers contain some evidence related to the effect of aviation on ambient air quality (*8*). Methods used in these studies include emission analyses, dispersion modeling, and ambient measurement studies. Unfortunately, each method has flaws that make general scientific conclusions difficult. Emission analyses are readily understandable but are not directly comparable to air quality standards. Dispersion models explicitly relate aircraft emissions to air quality but can become so complex that they are hard to verify. They also suffer from unknown plume-rise and dispersion-simulation errors. Ambient measurement data are difficult to interpret since concentrations caused by airports are not readily separated from those caused by other metropolitan sources.

Results of previous studies are too lengthy to include here but are presented in detail in a recent technical report (*9*). Based on that and earlier reports, aircraft are not a direct cause of health and welfare effects. EPA thus would not have to issue aircraft emissions standards based on the maximum control possible. Less stringent but more cost-effective standards could be considered.

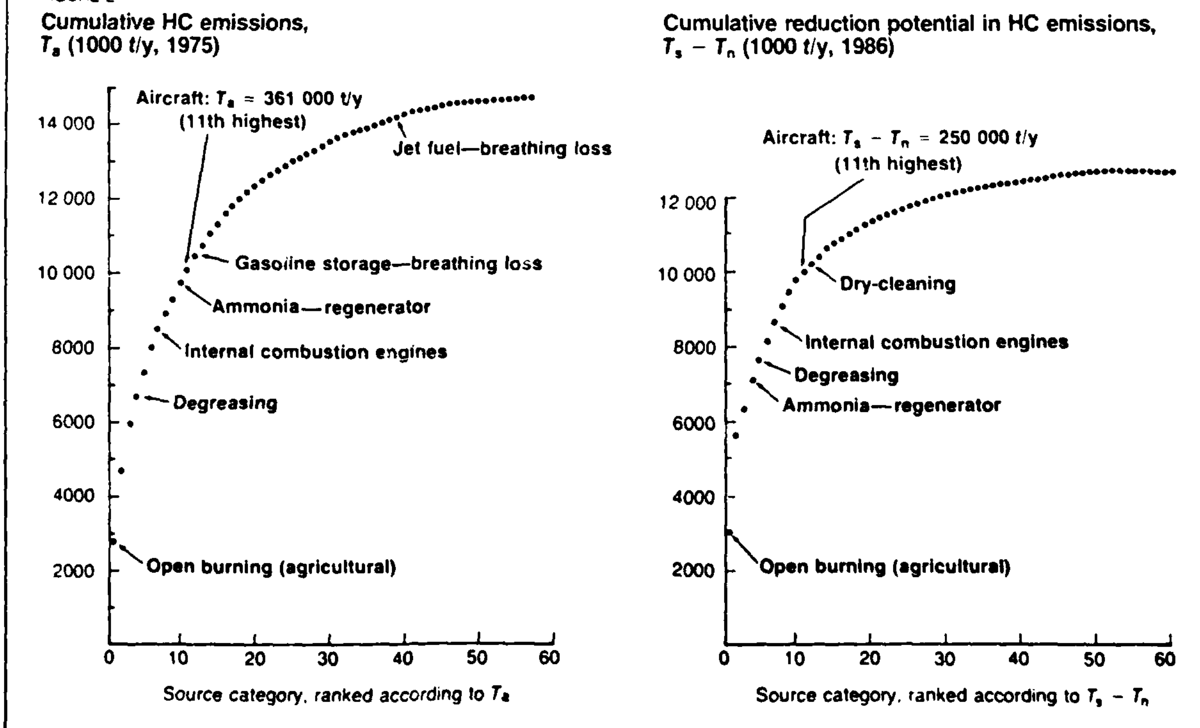
Aircraft may, however, contribute to some health and welfare effects. The pollutants of greatest concern are hydrocarbons (because of the serious nationwide ozone problem) and nitrogen oxides (because of the possible introduction of a short-term NO_2 standard).

Control technology now appears adequate to prevent objectionable emissions of visible smoke, but it may not be sufficient in the future if aviation fuels derived from shale oil are used. Carbon monoxide is not viewed as a serious problem from aircraft. Relaxed CO emission constraints may allow more emphasis by engine designers on HC or NO_x limitations. Potential problems from other substances in aircraft exhaust products have not been identified in the few scientific studies conducted to date.

Complete agreement with these conclusions among all investigators is not necessarily expected due to the large and often conflicting body of information that must be integrated; future scientific studies may alter current judgments. Two important issues of technical uncertainty remain:

• The significance of aircraft HC emissions in the atmospheric formation of photochemical oxidants is unknown. Aircraft emissions that result in ambient nonmethane hydrocarbon concentrations in excess of the 160-

FIGURE 2



$\mu g/m^3$ air quality guideline have been widely measured and modeled. This guideline is very crude, however, and is no longer recommended by regulatory agencies.

- The effect of aircraft emissions on maximum short-term NO_2 concentrations is questionable. The evidence that aircraft could produce hourly NO_2 concentrations in the 0.2–0.5-ppm (parts per million) range is suggestive but certainly not conclusive. The conversion rate of NO emissions to NO_2 in conjunction with atmospheric dilution is not well understood. Also, the short-term NO_2 ambient standard, to be used as a measure of health effects, has not yet been issued.

Whether any pollutant from aircraft *contributes* to adverse health or welfare effects is therefore still debatable and not easily resolved from current scientific information.

Controls and costs

Debate over the air quality effect of aircraft would be less important if controls could readily be implemented to reduce even further what many consider already to be a small source. Unfortunately, there are considerable engineering problems and costs involved. A basic understanding of the pollutant formation process is needed to appreciate the proposed control techniques and their difficulties.

The primary combustion zone of an aircraft engine (Figure 3) is characterized by a high temperature (T) and a fuel-rich condition (indicated by a high equivalence ratio (ϕ), the local fuel-air ratio divided by the stoichiometric fuel-air ratio). Dilution air causes low temperatures and fuel-lean conditions in the secondary zone. High HC concentrations in the combustor occur initially as the fuel vaporizes, but then rapidly decrease. CO is formed in fuel-rich conditions but can be substantially oxidized to CO_2. Nitric oxide (NO) is formed at high temperatures when sufficient oxygen is available and is typically "quenched" from decomposition by the cool secondary air flow. Particulate matter is formed when fuel droplets are inadequately vaporized prior to combustion. Oxidation of the carbonaceous particles proceeds unless "frozen" by low-temperature air such as that near the combustion liner (*10*).

The technology for control of aircraft engine emissions is detailed in other sources (*11–13*); however, some general approaches are outlined in Table 1. The conventional technologies, effective for HC, CO, and smoke, have been generally demonstrated but

FIGURE 3
Pollutant formation in a gas turbine

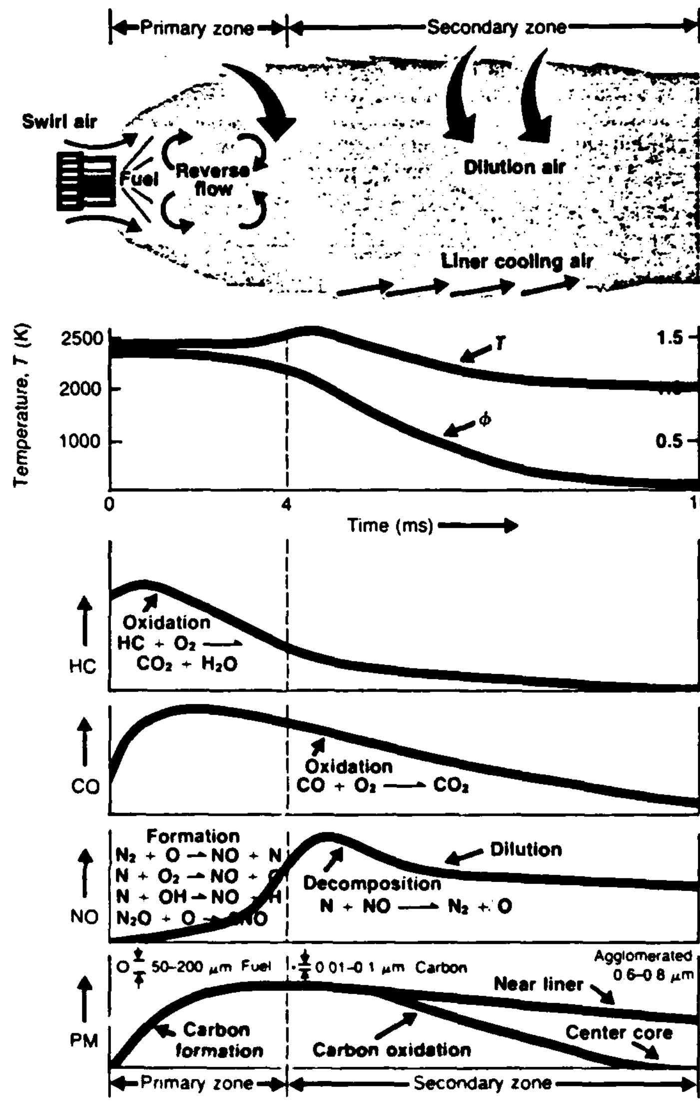


TABLE 1
Aircraft engine emission control technology

Conventional combustor emission control technology (HC, CO, and smoke control)	
Fuel sectoring	Restrict fuel to portion of combustor Better fuel atomization Higher flame temperature
Enrich primary zone	Reduce primary airflow for higher flame temperature
Delay dilution air	Promote CO consumption
Air blast	Use venturi to breakup fuel droplets
Advanced combustor emission control technology (NO_x control in addition to other pollutants)	
Staged fuel injection	Provide both pilot and main-stage ignition Higher flame temperature at idle Minimize peak temperatures at high power
Variable geometry	Optimize airflow for thrust condition

many require additional testing as dictated by the degree of control required. The advanced technologies needed for any appreciable NO_x control would require additional development, testing, and evaluation prior to implementation. Emission controls are currently the prime motivation for redesigning engines using current jet fuels. Potential improvements in thrust, fuel economy, or durability would not otherwise warrant such complex new designs. A future switch to fuels from alternative energy sources such as oil shale might necessitate these advanced technology concepts to maintain engine durability, however.

Implementation of conventional and advanced combustor technologies for large commercial aircraft engines could cost $1.5–3 billion over a 10-year period (*14*). Whether the cost of controls exceeds the air quality benefits is difficult to answer. Data in a recent cost-effectiveness study (*15*) suggest that aircraft engine controls for HC and CO that cost several hundred dollars per ton of emission reduction are in line with some other EPA control strategies. NO_x controls, possible only with advanced combustor technology, cost a projected $3400–9700 per ton (two to 10 times higher than NO_x controls for other sources). Present aircraft emission levels would not appear to justify these kinds of expenditures.

Unless constrained by NO_x regulations, however, future aircraft will use more efficient engines with higher pressure ratios and combustor inlet temperatures, which will in turn increase NO_x emissions. Difficult policy decisions will have to be made. The options are:

- allow future engine efficiency improvements accompanied by large aircraft NO_x increases
- limit future NO_x emission levels, which may constrain engine efficiency improvements
- force the high costs of undeveloped advanced combustor technologies in order to have both more efficient engines and reduced aircraft NO_x emissions.

Regulatory outlook

Meanwhile, the regulatory picture remains complicated. The military, which is not subject to EPA standards, has set its own emissions "goals" as a design limit for future engines. These goals are intended to strike a compromise between the many design considerations—including performance—and do not make emissions an overriding factor (*16*).

EPA, which has made numerous revisions to its original 1973 standards (*17*), is still in the process of considering changes proposed in 1978 (*18*). These specify mass emissions per unit of thrust and are based on emission measurements made across the engine exhaust exit at various engine modes, fuel flows, and thrust levels. These measurements are then multiplied by EPA time-in-mode factors to estimate emissions over the longest times needed for aircraft approach, landing, taxiing, shutdown, start-up, takeoff, and climbing to 3000 feet.

A simpler set of standards were recently recommended by the International Civil Aviation Organization (*19*). These would not result in as great an emission reduction but would provide some controls for future engine emissions and would presumably make engine certification more predictable. They apply to the statistical mean of engines certified rather than the upper limit intended by EPA standards.

These recommendations, the cost-effectiveness of control technologies, and the absence of a proven link between aircraft emissions and health and welfare effects are all key issues. Their net effect on EPA's reconsideration of the aircraft air pollution regulations remains to be seen.

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